

Naturally Occurring Affect Predicts Verbal and Spatial Working Memory Performance

by

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A thesis

submitted in partial fulfilment

of the requirements for the degree of

Master of Arts

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St. Catharines, Ontario

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Abstract

Some research has shown that induced affective states that vary in valence have differential effects on verbal and spatial working memory performance, such that positive affect improves verbal working memory and impairs spatial working memory, while negative affect improves spatial working memory and impairs verbal working memory. However, other research using similar mood induction and working memory tasks, has supported a nonspecific influence of affect on working memory performance where fear impairs, and positive affect improves, both verbal and spatial working memory. The present study investigated whether individual differences in naturally occurring trait and state affect could predict verbal and spatial working memory performance across six working memory tasks. Valence uniquely predicted working memory performance over and above arousal and the interaction of valence and arousal which were not significant predictors. Positive affect was associated with better WM performance, while negative affect was associated with worse working memory performance. This pattern held across both verbal and spatial working memory tasks, but was observed more strongly with 2-back working memory tasks than with complex span working memory tasks. These findings suggest that, in contrast to research demonstrating differential effects of affective states on verbal and spatial working memory performance, naturally occurring affect demonstrates a modality independent effect on working memory.

Acknowledgements

I would first like to thank my supervisor Dr. Karen Arnell for her countless hours of contribution to this thesis project. Thank you for not letting me write a 300 paged thesis about everything I know about cognition in general. I would also like to thank my committee members Dr. Stephen Emrich and Dr. Cathy Mondloch for their helpful feedback and useful perspectives. I would like to offer my thanks to my friends and family for putting up with my hyperbolizing of academic related goals. Thank you once again everyone, it has been quite the journey.

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List of Abbreviations

dIPFC	=	Dorsal lateral prefrontal cortex
EEG	=	Electroencephalogram / Electroencephalography
fMRI	=	Functional magnetic resonance imaging
LTM	=	Long-term memory
PET	=	Positron emission tomography
PFC	=	Prefrontal cortex
STM	=	Short-term memory
vIPFC	=	Ventral lateral prefrontal cortex
WM	=	Working memory

Naturally Occurring Affect Predicts Verbal and Spatial Working Memory Performance

Working Memory

Every day, individuals encounter situations that require them to remember material for a short period of time (e.g., remembering a phone number you just looked-up long enough to call it, or remembering the start of a sentence long enough to make it come together meaningfully in the end). Working memory is an important component of directing goal-oriented behaviour (Kane & Engle, 2003; Swanson & Fung, 2016). Although examined from various viewpoints, working memory can be defined generally as the goal-directed, active maintenance and manipulation of information (Baddeley, 2012; Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005; Kane & Engle, 2002). Critically, the maintenance and manipulation of information takes place when the information is not accessible in the immediate environment (Baddeley, 2012). Using multiple methodologies, several individual difference studies have shown that good working memory performance is associated with good performance on several measures of problem solving (Conway et al., 2005; Swanson & Fung, 2016), executive attention (Engle, 2002), learning (Fung & Swanson, 2017), reading comprehension (Daneman & Carpenter, 1980; Swanson, 2008), and standardized test performance (Conway et al., 2005; Swanson & Fung, 2016).

Given that WM is associated with several cognitive measures, it is important to examine predictors of individual differences in working memory. Individual differences in naturally occurring affect predicts performance on several cognitive tasks such as attentional breadth (e.g., Arnell, Chung, Dale & MacLean, submitted) dual-task attention (MacLean & Arnell, 2010; MacLean, Arnell & Busseri, 2010), and conceptual breadth (Arnell et al., submitted; Middlewood, Gallegos & Gasper, 2016). In order to investigate affect and WM interactions, previous studies have induced participants into various mood states and subsequently asked them

to perform WM tasks (e.g., Gray 2001; Gray, Braver & Raichle, 2002; Storbeck, 2016; Storbeck & Maswood, 2016; Vytal, Cornwell, Letkiewicz, Arkin & Grillon, 2013; Yang, Yang & Isen, 2013). Here I will examine whether individual differences in naturally occurring affect can predict performance on WM tasks that differ in verbal/spatial domain and how information is manipulated. Because some research has shown different effects of affect on different WM tasks, I first outline the different types of WM tasks (e.g., complex span and n-back) as well as their neurological underpinnings.

Working Memory

Working memory tasks require the active maintenance and manipulation of information. For example, the backward digit span task requires participants to report sequences of digits backwards in reverse order, thus requiring mental manipulation to reorder the digits (Baddeley, 2012). A popular WM task that requires both the maintenance and updating of WM stimuli is the n-back task where a series of stimuli are presented at a rate of one every two or three seconds, and participants report whether or not the current stimulus is the same as the stimulus shown “n” stimuli prior. For example, in the standard verbal 2-back task, participants report whether or not the current letter is the same as the letter presented two items earlier in the list. The n-back task can also be performed with non-verbal stimuli by asking participants to report whether shapes or locations match the shape or location from n-back (Redick & Lindsey, 2013). Notice that the n-back task requires participants to retain the current item and previous two items in WM, and requires them to continuously update these items and make a discrimination while avoiding interference from 1-back items, and items that are 3 or more back (Gevins & Cutillo, 1993; Owen, McMillan, Laird & Bullmore, 2005).

Some WM tasks demand the active maintenance and manipulation of information by requiring participants to retain information while performing additional interference tasks that prevent rehearsal of the to-be-remembered information, and require attentional resources to filter out goal-irrelevant information (Awh, Vogel & Oh, 2006; Shipstead, Lindsey, Marshall & Engle, 2014; Unsworth, Fukuda, Awh & Vogel, 2014). For example, the Reading Span task developed by Daneman and Carpenter (1980) requires participants to read each sentence aloud and remember the last word of a varying number of experimenter-administered sentences. This task is typically scored by adding one sentence at a time until the number of words correctly recalled by the participant asymptotes or declines. Notice that, when completing the Reading Span task, reading aloud the subsequent sentence prevents active rehearsal of the last word of the previously presented sentences, and that the words other than the last word provide competing information.

Kane, Engle and colleagues have automated and adapted the Reading Span Task created by Daneman and Carpenter (1980) into a set of popular working memory span tasks such as the Operation Span Task where participants try to recall a series of “n” words after reporting out-loud the content and accuracy of a simple math equation such as $(3 \times 2) - 2 = 4$ between the presentation of each new word. Participants receive alternating words and equations until prompted to recall all of the words in series, with the series length varying from 2 to 7 words. Similarly, in the Symmetry Span Task (Engle, 2005 & Unsworth, Heitz, Schrock), participants try to remember a series of “n” spatial locations (coloured squares within a 3 X 3 matrix) while judging the symmetrical nature of a block pattern shown after each matrix location. At the end of each trial, participants are asked to report the matrix locations in the correct order. Notice that these tasks require both the active maintenance of relevant information (e.g., holding the locations in memory), along with the management of irrelevant information (e.g., performing the

symmetry task without saving the memory-irrelevant symmetry pattern information). Therefore, while short-term memory tasks focus on the maintenance of information, working memory tasks focus on the maintenance and management of information, with management requiring controlled attention.

According to state-based models of working memory, attention is directed to internal stimulus representations in a goal directed manner (D'Esposito & Postle, 2015; Kane et al., 2002). The representations are actively rehearsed in order for the representations to exist in a usable form to direct behaviour (D'Esposito & Postle, 2015). Some models of WM posit that the prefrontal cortex manages the executive control aspect of WM, with the material itself being held in more posterior mnemonic buffers (e.g., Curtis & D'Esposito, 2003; Postle, Berger, & D'Esposito, 1999). Indeed, the prefrontal cortex (PFC) has been shown to play a critical role governing controlled attention during working memory tasks (Kane & Engle, 2002). For example, lesion studies have shown that patients with damage to the prefrontal cortex show deficits in tasks that require working memory and sustained attention (Conway et al., 2003; Engle et al., 1999; Kane and Engle, 2002). Research using imaging techniques (e.g., fMRI) has demonstrated the importance of the PFC when actively using attention for directing goal-relevant behaviour (e.g., maintaining and filtering information) (D'Esposito et al., 1999). Specifically, using working memory and short-term memory paradigms, D'Esposito et al. (1999) provided imaging evidence that both the dorsal lateral prefrontal cortex (dlPFC) and ventral lateral prefrontal cortex (vlPFC) are involved in the maintenance and manipulation of information, however the dlPFC was shown to have more activation when participants were manipulating information as opposed to simply holding information in memory (Owen et al., 2005). Similarly, Awh, Jonides, Smith, Schumacher, Koeppel and Katz (1996) used Positron Emission

Tomography (PET) to show that different brain areas are involved in the active updating vs. storage of verbal information. More specifically, using a recognition task that simply requires maintenance of information, and the 2-back task that requires updating of WM contents, Awh et al. (1996) showed that storage mechanisms predominantly activated areas in the parietal lobe. In contrast, activation related to updating was predominately dependent on frontal areas.

Critically, both complex span and n-back tasks require the use of the prefrontal cortex (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998; Della Sala et al., 1998; Kane and Engle, 2002). Activation varies depending both on task requirements (e.g., complex span or n-back) and stimulus characteristics (e.g., verbal or spatial) (e.g., Christophel, Klink, Spitzer, Roelfsema, & Haynes, 2017). Imaging work from Chien, Moore, and Conway (2010) has shown that the medial temporal lobe is critical when completing complex span tasks. More specifically, using fMRI adapted verbal and spatial complex span tasks, Chien and colleagues have shown that compared to n-back tasks, completing complex span tasks requires recruitment of the medial temporal areas (see also Faraco, Unsworth, Langley, Terry, Zhang, Miller, 2011). In contrast, extensive imaging work has shown that frontal parietal networks are engaged when completing n-back tasks (Owen, McMillan, Laird & Bullmore, 2005). For example, a meta-analysis executed by Owens and colleagues suggests that the bilateral and medial posterior parietal cortex is used for the storage and rehearsal of short-term information when completing the n-back task, but the prefrontal cortex is used for management operations such as prioritizing and sequencing relevant information (Owen et al., 2005).

Verbal versus Spatial WM.

Several studies have shown that there are dissociable areas involved in storing verbal and spatial information (Courtney et al., 1996; Postle et al., 2004; Smith et al., 1996; Smith et al.,

1995). The distinction between how verbal information (e.g., letters and words) and non-verbal information (e.g., locations and patterns) is maintained for working memory has also been investigated in early case studies observing patients with atypical neuroanatomy (e.g., lesions and damage) (Baddeley, 2012; D'Esposito & Postle, 2015). In a study by Warrington et al. (1971), patients who had suffered brain lesions to the left hemisphere displayed deficits when having to remember verbal information in short-term memory. This was supported by Vallar et al. (1996), where patients with left hemisphere lesions showed intact phonological judgement, but had deficits in verbal short-term memory. The left hemisphere has also been shown to play an important role in working memory tasks using object stimuli. In a study by Smith et al., (1995), participants were asked to report whether a probe geometric figure matched one of two previously shown figures. Interestingly, PET activations demonstrated left hemisphere activation similar to tasks that require verbal working memory. In contrast, when participants were asked to do a similar task using spatial information (e.g., matching the location of presented dots), imaging evidence showed activation in the right hemisphere. This hemispheric dissociation for object and spatial information in working memory is further supported by extensive imaging and behavioural evidence (Courtney et al., 1996; Courtney et al., 1998; Smith & Jonides, 1999; see also the meta-analysis by Owen et al. 2005).

The distinction between verbal information and spatial information in the context of working memory is further highlighted when examining stimulus-specific rehearsal mechanisms. For example, when having to maintain phonological information in memory via active rehearsal, Smith et al. (1999) showed that activation in the left hemisphere is associated with rehearsing verbal information compared to in the right hemisphere. In contrast to phonological rehearsal which is typically used for the maintenance of verbal information in working memory, extensive

imaging work has shown similar domain-specific attention-based spatial rehearsal mechanisms for spatial working memory (Postle et al., 2004; Awh et al., 1998; Awh et al., 1999). For example, in a study by Awh et al., (1999), participants were shown non-alphabetical characters in various locations. Participants were asked to identify if a subsequent probe was in the same spot as the previously shown non-alphabetical character. Results from this study showed spatially oriented shifts in attention to keep spatial information active in memory, predominantly using the right hemisphere (Awh et al., 1999; see also Owen et al. 2005 meta-analysis showing left ventrolateral prefrontal cortex activation for verbal identity monitoring during a verbal 2-back task, but activation in right hemisphere regions associated with spatial location monitoring in spatial 2-back tasks).

In addition to evidence suggesting that separate areas used for rehearsal of verbal versus spatial information, several studies provide supporting evidence for domain specific interference (Sala, Gray, Baddeley, Allamano, & Wilson, 1998; Shah and Miyake, 1996; Postle, Desposito, & Corkin, 2005). For example, in a study by Postle et al. 2005, participants completing n-back tasks that included either object (e.g., shapes) or spatial (e.g., location oriented stimuli) information. Results showed that object n-back performance was impaired when presented with verbal distractors (e.g., words), compared to the spatial distractors (e.g., jittering shapes/motion). In contrast, spatial n-back performance was impaired when presented with motion distractors, compared to the verbal distractors. These findings have been extended using different working memory tasks and other similar types of spatial and verbal distractors (Baddeley, 2012).

As noted above, WM performance has been shown to predict other performance measures such as problem solving and standardized test scores. Verbal working memory (e.g., letters and words) and non-verbal working memory (e.g., patterns and locations) differentially

predict individual differences on verbal or non-verbal tasks (Carpenter, Miyake & Just, 1995; Kane et al., 2004). For example, Shah and Miyake (1996) showed that performance on the Reading Span predicted performance on a verbal standardized test (SAT), better than the Symmetry Span. In contrast, performance on the Symmetry Span predicted performance on standardized tests that require the use of one's spatial abilities (e.g., spatial orienting) better than Reading Span. Both span tasks were correlated with both standardized tests, which also demonstrates the utility of a unitary working memory process.

Affect and Working Memory

In addition to the verbal and spatial distinction being lateralized, there are hemispheric differences for affective states that vary in motivational direction (e.g., approach or withdrawal) with approach motivation being associated with the left hemisphere and withdrawal motivation being associated with the right hemisphere (Carver & White, 1994; Gray et al., 2002). Models of affect identify distinct qualities of valence (i.e., how positive or negative one subjectively feels), arousal (i.e., how intensely stimulated one subjectively feels), and motivational intensity (i.e., the degree to which one has the impulse to approach or withdraw from a stimulus) (Barrett & Russell, 1998; Gable & Harmon-Jones, 2010; Harmon-Jones et al., 2017; Tellegen, Watson, Clark & Clark, 1999). Motivational intensity can be low as when there is not a strong desire to approach or avoid a stimulus, or high as in the desire to approach a chocolate cake or withdraw from a dirty washroom (Harmon-Jones, Gable & Price, 2013).¹ Given that approach and

¹ Although motivational intensity and arousal cannot be used interchangeably in non-emotional contexts (e.g., physical exercise), when placed into the emotional context, motivational intensity and arousal have been shown to closely map onto each other (Harmon-Jones et al., 2013). For example, discrete emotions such as fear and disgust are emotions high in withdrawal motivation, and emotions such as desire and anger are emotions high in approach motivation. Similarly, all of these emotions are highly arousing. Emotions such as sadness, contentment, and amusement are low in motivational intensity and often elicit low levels of arousal (Gable & Harmon Jones, 2010).

withdrawal states are thought to differentially activate left and right hemispheres respectively, much WM research has examined whether these mood states influence verbal and spatial WM differently.

Researchers have employed various mood induction procedures to investigate the influence of induced affective states on verbal and spatial working memory performance (Gray, 2001; Gross & Levenson, 1995; Hewig, Hagemann, Seifert, Gollwitzer, Naumann, & Bartussek, 2005). Gray (2001) showed that after watching an approach video (stand-up comedy), participants performed better on a verbal 2-back task compared to a spatial 2-back task, but, after watching a withdrawal video (horror movie), participants performed better on a spatial 2-back task compared to a verbal 2-back task. Gray (2001) explained these results in terms of hemispheric differences. Extensive work has shown hemispheric differentiation for approach-related affective states and withdrawal-related affective states (Carver & White, 1994; Sutton & Davison, 1997; Heller, Nitschke, & Muller, 1998). Specifically, greater left prefrontal activity has been associated with greater approach motivation and greater right prefrontal activity has been associated with greater withdrawal motivation. For example, cues associated with reward were associated with left hemisphere activity, whereas cues associated with negative affect (e.g., anxiety provoking cues) were associated with greater activity in the right hemisphere (Sutton & Davidson, 1997). Greater left hemisphere prefrontal activation, relative to right frontal activation, has been associated with greater optimism (DePascalis, Cozzuto, Carara & Alessandri, 2013), greater dispositional anger (Harmon-Jones & Allen, 1998), an increase in risky decision making (Fecteau, Knoch, Fregni, Sultani, Boggio, & Pascual-Leone, 2007), approach postures such as leaning in and reaching out (Price & Harmon-Jones, 2010), higher behavioral activation scores (BAS) reflective of greater dispositional approach motivation (e.g.,

greater sensitivity to reward and positive stimuli) (Harmon-Jones & Allen, 1997), and narrowed attentional and conceptual breadth (Gable & Harmon-Jones, 2008; Gable et al. 2013). In contrast, greater right than left hemisphere prefrontal activation has been associated with increased responses under stress (Dusing, Tops, Radtke, Kuhl, & Quirin, 2016), increased risk of depression (Coan & Allen, 2004), and low approach postures such as leaning back (Price & Harmon-Jones, 2010), consistent with withdrawal motivation. So, the left hemisphere is critical for both the maintenance of goals associated with approach motivation, and the processing of verbal information (Gray, 2001), but the right hemisphere is posited to be associated with the maintenance of withdrawal related goals (Gray, 2001), and is implicated in the maintenance of spatial information (Awh et al., 2006). according to Gray (2001), when an individual's affective state activates the hemisphere that preferentially processes WM information used in the 2-back task, performance is enhanced relative to when the affective state and type of information rely on different hemispheres.

Gray, Braver and Raichle (2002) used fMRI with a similar video mood induction paradigm and 3-back procedure using words and faces (as opposed to letters and locations). They found that when participants were induced into a pleasant approach mood, they performed better on the 3-back task with words than faces. However, when induced into an unpleasant withdrawal mood participants performed better on the 3-back task with faces than words, and worse on the 3-back task with words than faces, replicating the pattern found by Gray (2001). fMRI data from Gray et al. (2002) further supported the double dissociation in that the lateral prefrontal cortex showed greater neural activation for conditions that had lower behavioural accuracy (i.e., pleasant mood with faces and unpleasant mood with words) than for conditions that had higher behavioural accuracy (i.e., pleasant mood with words and unpleasant mood with faces),

suggesting that lateral PFC activation reflects how much top-down support is needed to perform the task. Furthermore, when examined from an individual differences perspective, participants' lateral PFC activity during a given task predicted their behavioural performance for that task. This is consistent with models of working memory focusing on the goal driven use of the PFC to keep up with task demands, but also shows that factors such as affect can interact with the nature of the task to influence processing at this level (Gray et al., 2002). However, this same activation pattern was found in both left and right IPFC, and the Emotion X Words/Faces interaction did not interact with left/right PFC activation. This casts doubt on Gray's (2001) simple explanation that approach motivation benefits verbal material simply because they are both supported by the left hemisphere, and that withdrawal motivation benefits spatial material simply because they are both supported by the right hemisphere.

Storbeck (2016) replicated the Gray (2001) pattern of behavioural results even after participants were psychologically fatigued after completing an incongruent Stroop task. Consistent with Gray (2001; 2002), the results showed that participants in a happy mood performed better on the verbal 2-back while participants in a negative mood performed better on the spatial n-back task. Storbeck (2012) also induced participants into an approach-motivated positive mood or a withdrawal-motivated negative mood prior to performing a spatial or verbal n-back task, but this time it was followed by an effortful task requiring self-control (e.g., incongruent Stroop). Participants who performed in the incompatible conditions (verbal in negative mood or spatial in positive mood) performed worse on the subsequent self-control task than participants who performed in the compatible conditions (verbal in positive mood or spatial in negative mood), leading Storbeck to suggest that the incompatible conditions require increased effortful self-control which then became depleted. Storbeck (2016) explained these

findings in terms of the Goal Compatibility Theory which proposes that emotions anticipate the potential requirements of the environment and facilitate reduced effort when performing goal directed behaviour. This reduced effort needed for compatible emotional states and stimuli can lead to enhanced behavioural performance (Gray, 2001; Gray et al. 2002; Storbeck, 2016), reduced lateral PFC activations (Gray et al., 2002), and reduced reliance of self-control resources (Storbeck, 2012).

Using similar mood induction procedures, but verbal and spatial complex span tasks, Storbeck and Maswood (2016) provided evidence for a different pattern of affect and working memory interactions. These authors induced participants into a negative low arousal mood (sadness), low arousal positive approach mood (happy), or a neutral mood. Results showed that participants induced into a positive mood were more accurate than the negative and neutral mood groups on both verbal and spatial working memory span tasks. In contrast to what Gray (2001; Gray et al., 2002) would hypothesize, participants in an induced positive mood showed improved, not impaired, performance on the spatial working memory span task. Storbeck et al., (2016) explained this discrepancy with previous n-back results in terms of: 1) complex span tasks requiring greater executive control than n-back tasks, and 2) positive affect having a beneficial effect on executive control that happens over and above the influence of affect on domain specific characteristics of the working memory task (e.g., verbal or spatial). Indeed, induced positive affect has been shown to benefit the executive control aspect of working memory more than it benefits a short-term memory task that requires only the maintenance of information (Yang, Yang & Isen, 2013).

Similar to findings from Storbeck and Maswood (2016), Vytal et al. (2013) have shown a unilateral effect of affect on working memory performance. Specifically, participants induced

into an anxious mood via potential shock threat showed impaired n-back performance across task domain (e.g., verbal and spatial) for 1- and 2-back compared to the control group (no shock threat), but only spatial n-back performance was negatively affected by shock threat in the 3-back condition. In-line with Storbeck and Maswood (2016) who proposed that happiness could replenish cognitive resources, Vytal et al. (2013) posited that anxiety consumed cognitive resources, leaving fewer for the WM task.

The Current Thesis

Together, the above findings provide supporting evidence that induced affective states can influence working memory performance. However, the pattern is somewhat inconsistent. Some studies (Gray, 2001; Gray et al, 2002, Storbeck, 2016) show that positive mood enhances verbal WM and impairs spatial WM, and that negative mood enhances spatial WM and impairs verbal WM. However, other studies have shown that positive affect improves, and negative affect impairs, WM performance more generally (Storbeck & Maswood, 2016; Vytal et al., 2013). Thus far it has not yet been investigated whether naturally occurring affect can predict WM. Where previous researchers have induced participants into various affective states, the present study measures naturally occurring affect. This individual differences approach is beneficial by reducing the ambiguity that is associated with how an individual is subjectively experiencing the induced affective state. For example, just because an affective manipulation is labelled as positive and approach oriented does not mean that it produces a positive approach state in any or all of the participants. In contrast, simply asking participants to report how they feel on average from day to day (i.e., trait affect), and in the moment (i.e., state affect), is likely to be a more valid indicator of their emotions.

Secondly, whereas previous studies have included verbal and spatial n-back tasks (e.g., Gray 2001; Gray et al., 2002; Storbeck, 2016; Vytal et al., 2013), or verbal and spatial complex span tasks (Storbeck & Maswood, 2016; Yang et al., 2013), no study has included verbal and spatial equivalents of both the complex span and n-back WM tasks in the same study. Previous inconsistent results on affect and WM may be due, in part, to the use of complex span tasks in some studies and n-back tasks in other studies, as different task demands for span tasks and n-back tasks could lead to different roles for affective states. After performing a meta-analysis of the WM data, Redick and Lindsey (2013) concluded that complex span tasks and n-back tasks cannot be used interchangeably to describe working memory processes. However, in the affect and WM literature complex span tasks and n-back tasks appear to be used interchangeably, and have never been included together in a single study. In the present study I will investigate how affective states influence both verbal and spatial complex span tasks and verbal and spatial n-back tasks in the same study.

Thus, in the current thesis I investigate the role of self-reported naturally-occurring (dispositional) affect in predicting working memory performance varying in domain (e.g., verbal versus spatial), and task (e.g., complex span versus n-back), resulting in the inclusion of verbal and spatial n-back tasks and verbal and spatial complex span tasks. Participants completed the circumplex self report affect questionnaire (Feldman-Barrett & Russell, 1998), that allows trait affect to be measured as a function of valence, arousal, and the interaction of valence and arousal (see Appendix A). They also completed the Emotions Report Form (ERF; Fredrickson & Branigan, 2005) that provides measures of state positive and negative state affect. This allowed me to examine state valence relative to trait valence, and to examine the roles of dispositional valence, arousal and their interaction separately for verbal and spatial n-back and complex span

tasks, letting me examine whether the influence of self-reported affect on WM, if any, is consistent across task and/or domain.

If cognitive resources are affected by differences in trait and state valence such that positive affect increases cognitive resources and negative affect consumes them, then in line with Storbeck and Maswood (2016) and Vytal and colleagues (2013), positive affect should be associated with better WM performance while negative affect should be associated with poorer WM performance for both types of tasks and stimuli. However, if it is about the match between motivational direction (i.e., approach/withdrawal) and stimulus domain (i.e., verbal/spatial) in terms of left and right hemispheres respectively, then in line with Gray and colleagues it is predicted that an interaction between valence and arousal should predict domain-specific performance. Specifically, positive affect that is high in arousal (resembling approach motivation) should predict better performance on verbal WM tasks and poorer performance on the spatial WM tasks. In contrast, negative affect that is high in arousal (resembling withdrawal motivation) should predict better spatial WM performance and poorer verbal WM performance.

Methods

Participants

Ninety-five Brock University undergraduate students (16 males and 79 females) were recruited using a university online recruitment platform, and received credit towards a course. Participants' ages ranged from 16 to 47 years old ($M = 21$, $SD = 5.89$). All participants reported English as their first language and normal or corrected to normal vision. In addition, all participants reported not having any mood disorders or being on any mood altering medications (e.g., antidepressants or anti-anxiety medications). During testing sessions, participants

completed the tasks individually. All participants performed the six tasks in the same order (see below) so that individual differences in working memory ability could be estimated separately from any possible task order effects.

Procedures

Participants were seated alone in a cubicle. After obtaining informed consent, participants were given an envelope containing five questionnaires². The participants were instructed that the questionnaires asked about their everyday feelings and behaviours. Critically, participants were shown that each questionnaire gave special instructions for the timeframe of the questionnaire (e.g., referring to how they feel generally on average, or in the moment). Participants completed the questionnaires alone, and returned them in a sealed envelope at the end of the session. After a short break, they then performed the working memory tasks in the following order: 1) the verbal 2-back task adapted from Gray (2001), 2) the spatial 2-back task adapted from Gray (2001), 3) the Symmetry Span task (Unsworth, Heitz, Schrock & Engle, 2005), 4) the Reading Span task (Unsworth et al., 2005), 5) a different spatial 2-back task using coloured matrices, and 6) a more typical verbal 2-back task with letters presented in a central location. Participants were then debriefed and any questions were answered. Working memory tasks were performed using a Dell desktop computer with a 17" CRT monitor running at 60Hz.

Questionnaire Measures

Circumplex Affect Questionnaire

² In addition to the Circumplex Affect Questionnaire (Feldman-Barrett & Russell, 1998), and Emotion Report Form (Ekman, Friesen, & Ancoli, 1980), participants completed the Behavioural Inhibition System and Behavioural Activation System Questionnaire (Carver & White, 1994), Positive and Negative Affect Schedule (Watson, Clark & Tellegen, 1988), and the Trait portion of the State and Trait Anxiety Inventory (Spielberger, 1989). These additional measures are not the focus of the thesis, and will not be discussed further.

In order to measure each participant's dispositional (naturally occurring) affect, participants completed the Circumplex Affect Questionnaire (Feldman-Barrett & Russell, 1998). The Circumplex Affect Questionnaire contains 77 items that measure self-reported naturally occurring affect that varies in valence (positive and negative), and arousal (activation and deactivation). Participants were asked to select on a scale from 1 (strongly disagree) to 5 (strongly agree) how much each statement applied to them on average (e.g., over the period of the last several weeks), and not as they felt at the current moment. Example items include: "I feel droopy and drowsy", "I feel proud of myself", and "I feel on edge". According to the Circumplex model of affect proposed by Feldman-Barrett & Russell (1998), affect can be conceptualized as a combination of two orthogonal dimensions labelled valence (e.g., pleasantness and unpleasantness) and arousal (e.g., activation and deactivation) (see Figure 1). Pleasantness scores were calculated for each participant by averaging all of the pleasantness items on the questionnaire regardless of activation level. Similarly, the unpleasant scores were calculated by averaging all of the unpleasant items in the questionnaire regardless of activation level. In order to calculate a measure of valence, the unpleasantness score was subtracted from the pleasantness score (e.g., representative of the valence dimension), such that greater positive values represented a greater preponderance of positive affect relative to negative affect. Activation scores were calculated for each participant by averaging all of the high activation items on the questionnaire regardless of valence. Similarly, deactivation scores were calculated by averaging all of the deactivation scores on the questionnaire regardless of valence. To obtain a measure of naturally occurring arousal, the deactivation score was subtracted from the activation score (e.g., representative of the arousal dimension) such that greater positive values represented greater activation relative to deactivation.

To obtain a measure of pleasant activation (PA), only the 16 items that were both pleasant and activated were averaged together. In order to obtain a measure of pleasant deactivation (PD), only the 11 items that were both pleasant and deactivated were averaged together. In order to obtain a measure of unpleasant activation (UA), only the 16 items were both unpleasant and activated were averaged together. In order to obtain a measure of unpleasant deactivation (UD), only the 11 items that were both unpleasant and deactivated were averaged together.

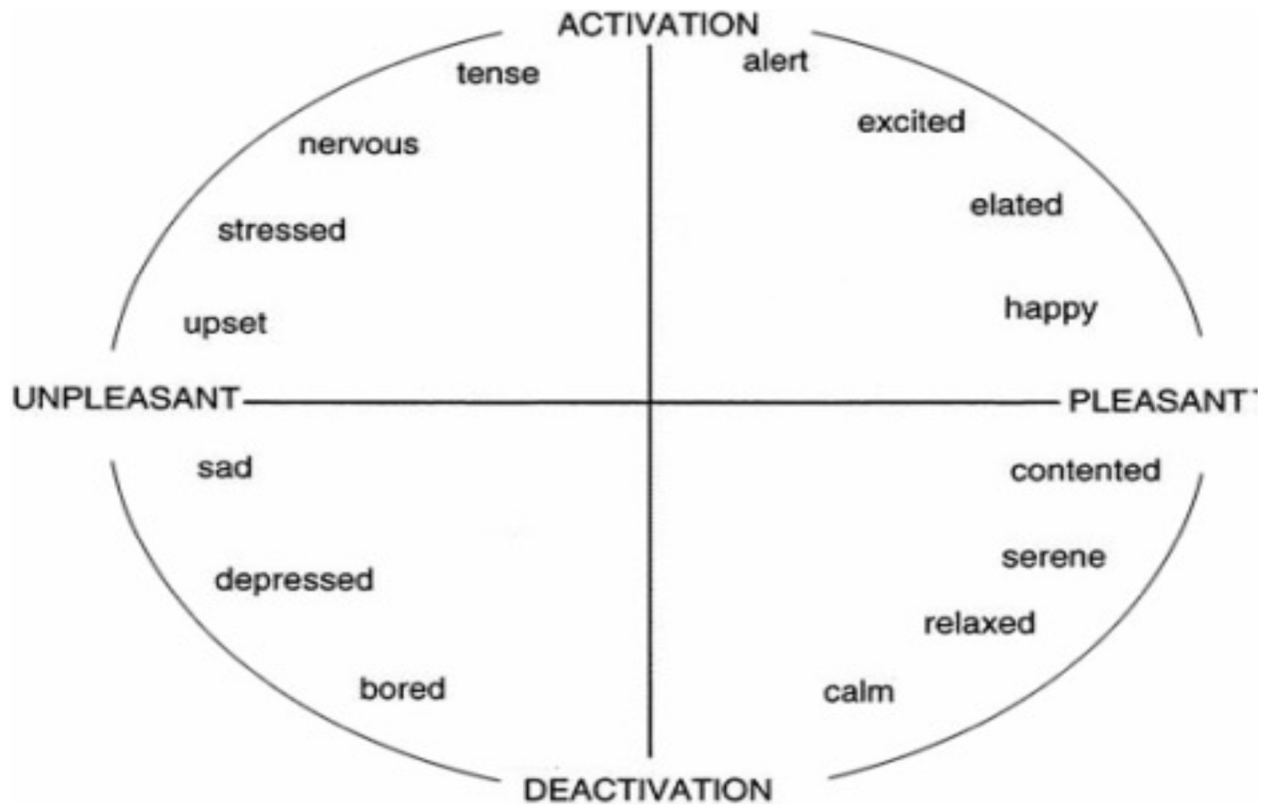


Figure 1. A depiction of the Circumplex Model of Affect proposed by Russell and Barrett (1988). In this model of affect, valence (unpleasant and pleasant) and arousal (activation and deactivation) are placed on separate ends of 2 orthogonal dimensions. In this conceptualization of affect, Unpleasant is shown to have both activated qualities (e.g., stressed) and deactivated qualities (e.g., sad). Similarly, pleasantness is shown to have both activated qualities (e.g., excited) and deactivated qualities (e.g., relaxed).

The Emotion Report Form

The Emotion Report Form (ERF; Ekman, Friesen, & Ancoli, 1980; Fredrickson & Branigan, 2005) was used to measure each participant's current affective state. The ERF (see Appendix B) is a 10 item inventory containing adjectives that describe five positive emotions (e.g., amusement, serenity) and five negative emotions (e.g., sadness, disgust). Participants were asked to indicate on a scale from 0 (none) to 8 (a great deal) how much of each adjective they were currently experiencing. For each participant, a positive score was obtained by summing all of the positive adjectives to obtain a total score out of 40, such that higher scores indicated more positive affect in the current moment. Similarly, a negative score was created by adding together all of the negative adjectives to obtain a total score out of 40 such that higher scores indicated more negative affect in the current moment. In order to obtain a measure of self reported state valence, the averaged negative items were subtracted from the averaged positive items, such that higher scores represent a preponderance of positive affect relative to negative affect.

Working Memory Tasks

2-Back Tasks: Gray (2001) Version

Participants performed a verbal 2-back task modelled on that of Gray (2001). Each verbal 2-back trial consisted of a rectangle with a random letter from b to z (excluding vowels) in the centre. The rectangle (containing the letter) randomly appeared in one of six locations on the screen (see top panel of Figure 2A). Participants were asked to ignore the location of the rectangle and indicate whether the letter presented to them on the current trial matched the letter presented two trials before (a target trial) or did not match (a non-target trial). Participants pressed "1" on the keyboard to indicate a target trial and "2" to indicate a non-target trial. One rectangle with a letter was presented every 3 seconds regardless of when, or if, the participant

had responded. Participants were told that only responses made before the next letter would be counted and that the program would continue to the next trial every 3 seconds even if a response was not made. Prior to performing the test trials, participants were familiarized with the concept of the 2-back task and given 30 practice trials. Participants were then shown 100 test trials (2 blocks consisting of 50 trials per block, each with 16 targets). In order to measure participants' accuracy, hits (correct responses on target trials) minus false alarms (incorrect responses on non-target trials) was calculated. Hits were scored as the percentage of correct targets out of 32 (16 targets per block) and false alarms were scored as 100 minus the percentage of correct non-targets out of 64 (34 non-targets per block, minus the first 2 trials from each block which were necessarily and obviously non-target trials).

For the spatial version of the Gray (2001) 2-back task, participants were shown the same stimuli used in the verbal 2-back task, but this time were asked to ignore the letter and indicate whether the current trial was a target based on whether the location of the rectangle matched the location of the rectangle presented two trials before (see bottom panel of Figure 2A). Critically, participants were reminded that target and non-target decisions were to be made independent of the letters that appeared in the center of the rectangle. Similar to the verbal 2-back task, participants were asked to press "1" to indicate a target and "2" to indicate a non-target, and a new trial began every 3 seconds whether or not a response had been recorded. Prior to performing the test trials, participants were given 30 practice trials. After completing the practice trials, participants completed two blocks (50 trials per block) of the spatial 2-back task, with 16 targets per block. Scoring was identical to that for the verbal 2-back task described above.

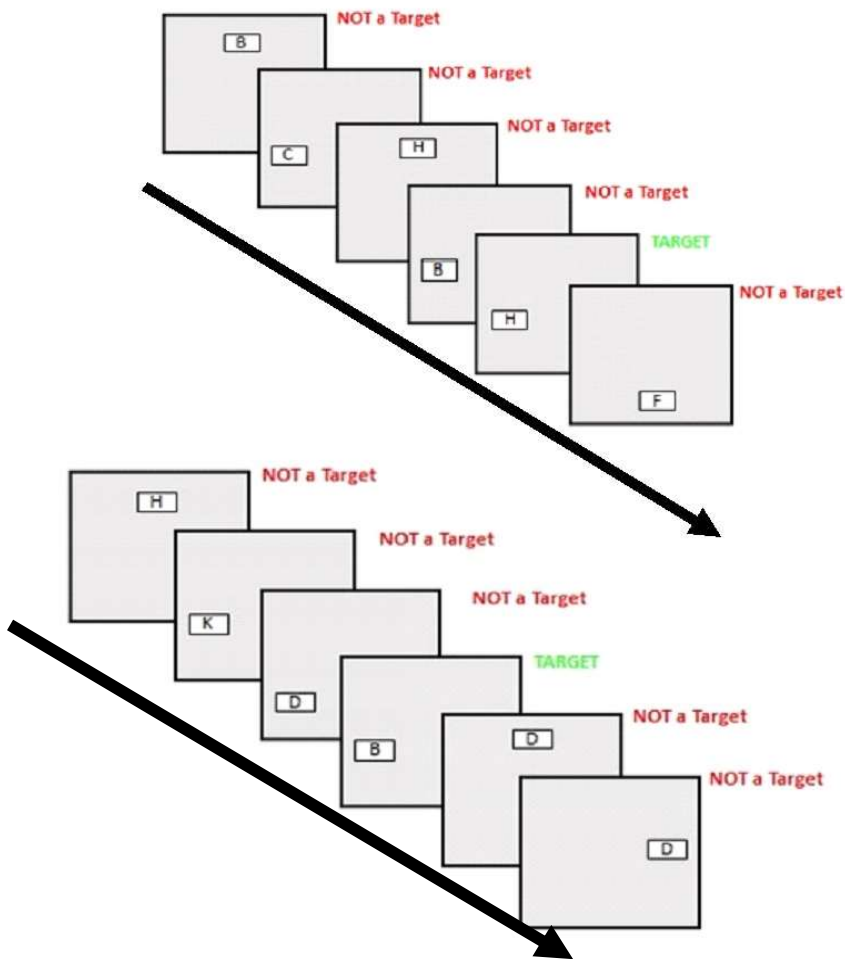


Figure 2A. A trial-by-trial schematic depicting the Gray Version of the 2-back paradigm. The top panel; shows the verbal 2-back paradigm. Following the direction of the arrow, the slides show the stimuli presented to the participant (one at a time). The red “NOT a Target” text indicates a non-Target trial where participants are instructed to press “2” indicative that the present letter does not match the letter presented 2 letters prior. The green “Target” text indicates a trial where participants are instructed to press “1”, indicative that the present letter was shown 2 letters prior. The bottom figure depicts the trial-by-trial schematic of the spatial 2-back paradigm. Instructions for the spatial 2-back are identical to the verbal 2-back previously explained, with the exception that Target and Non-Target decisions are to be calculated based on the location that the letter appears, not the based on the specific letter.

Verbal 2-back (Centrally presented)

Similar to the Gray (2001) version of the verbal 2-back task, participants were presented with one letter every 3 seconds. When presented with the letter, participants were asked to indicate whether the current letter matched the letter presented two trials prior (target), or did not match (non-target). However, unlike the Gray version of the Verbal 2-back, the letter stimuli were all presented at the same location in the center of the screen (see Figure 2B). Participants were asked to press “1” to indicate a target and “2” to indicate a non-target, and a trial new trial began every 3 seconds whether or not a response had been recorded. Participants completed 58 trials (29 trials per block, with 10 target trials per block). In order to obtain a measure of a participant’s accuracy, hits minus false alarms were calculated. Hits were scored as the percentage of correct target trials out of 20, and false alarms were scored as 100 minus the percentage of correct non-target trials out of 34. False Alarms were scored out of 34 instead of 38 because of the first 2 trials of each block necessarily being non-target trials.

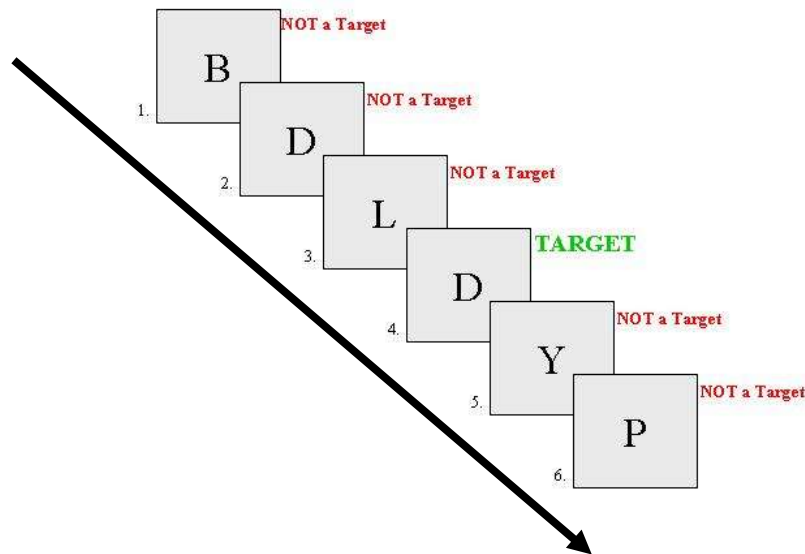
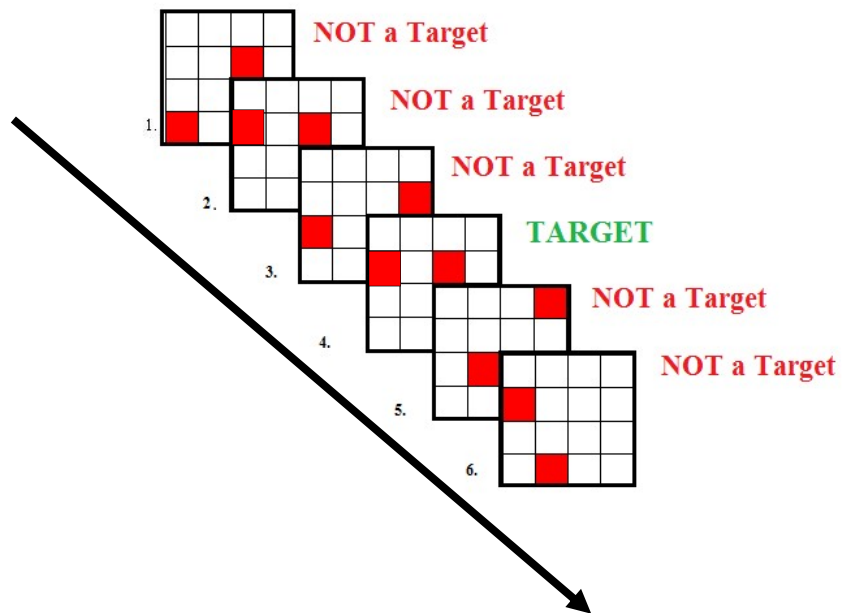


Figure 2B. A schematic depicting the Verbal 2-back paradigm that displayed centrally presented letters. Following the direction of the arrow, the slides show the stimuli presented to the participant (one at a time). The red “NOT a Target” text indicates a non-Target trial where participants are instructed to press “2” indicative that the present letter does not match the letter presented 2 letters prior. The green “Target” text indicates a trial where participants are instructed to press “1”, indicative that the present letter was shown 2 letters prior.

Spatial 2-back (Pattern Version)

Similar to the previously explained 2-back procedure, participants were presented with stimuli one at a time and were asked to indicate whether each stimulus was a target (press “1”) or a non-target (press “2”). However, instead of a letter, participants were presented with a 4x4 matrix with 2 of the possible 16 locations filled in red and the other 14 unfilled (see Figure 2C). Participants were asked to indicate a target when the red matrix pattern presented to them matched the pattern presented 2 trials prior, and a non-target when the pattern did not match. A matrix appeared in the centre of the screen every 3 seconds, and a trial new trial began every 3 seconds whether or not a response had been recorded. Participants completed two blocks of 29

trials (each with 10 targets). In order to obtain a measure of participant accuracy, hits minus false alarms were again calculated. Hits were scored as the percentage correct out of 20 target trials, while false alarms were scored as 100 minus the percentage correct out of 34 non-target trials given that the first 2 trials from each block were removed as they were consistently non-target trials.



Symmetry Span Task

The exact Symmetry Span task developed by Unsworth et al. (2005) was used. On each trial of this task a 4 by 4 matrix containing 16 squares was presented, with 1 of the possible 16 locations randomly filled in red. Participants were asked to remember the locations of the red squares, and to recall them in order when prompted at the end of each run of 2, 3, 4 or 5 trials. They did this by clicking, in order, on the location of the matrix when prompted. If they could not remember one location, they could also click to insert a blank and then carry on with the remembered items. Prior to each presentation of the to-be-remembered locations, participants were shown a pattern of black and white squares and were asked to make a speeded button press judgement as to whether the pattern was symmetrical or asymmetrical using the vertical axis. The symmetry task was used as a distraction in order to prevent active rehearsal of visuospatial information. Participants were told, correctly, that the symmetry judgements must be correct in order to receive points for the correctly recalled locations on that run. Participants were shown a total of 12 randomly ordered runs (three runs each of 2,3,4 and 5 – symmetry judgement - location trial combinations), for a total of 42 to-be remembered locations. See Figure 2D for a sample run containing three trials. In this example, participants would need to make a speeded symmetry judgment indicating that the first pattern was symmetrical and then try to remember the location of the first red box. They would then need to make a speeded symmetry judgment indicating that the second pattern was symmetrical and then try to remember the location of the second red box, and then make a speeded symmetry judgement that the third pattern was not symmetrical and remember the location of the third red box. At the end of the run, they would be asked to report the location of the three red targets in the correct order.

Prior to beginning experimental trials, participants first practiced the matrix location task alone for three runs, each with 2 or 3 trials, and then the symmetry task alone for approximately six trials where the symmetry judgement was timed, and their response time was used to pace the participant during the test trials. They also practiced both tasks together, as in the test trials, for three runs, each with 2 or 3 trials.

This task is scored using both partial credit and full credit scoring options (e.g., see Unsworth et al., 2005), both having a maximum score of 42. In both cases participants get credit only for trials where the symmetry judgment was correct. However, full credit scoring requires that all locations be correctly ordered within a run to get any points for that run, whereas partial credit scoring gives credit for any correct trial locations on that run, even if they are reported out of sequence. For example, if matrix locations 2, 6, and 7 were to be recalled, full credit scoring would give 0 out of 3 possible points for reporting locations 6, 7, and 1 in order, whereas partial credit scoring would give 2 possible points. Partial scoring credit is most often used due to its high reliability (Redick et al., 2012; Unsworth et al., 2005) and was used here as well, although the correlation between full and partial credit scoring on the symmetry task was strong ($r > .90$).

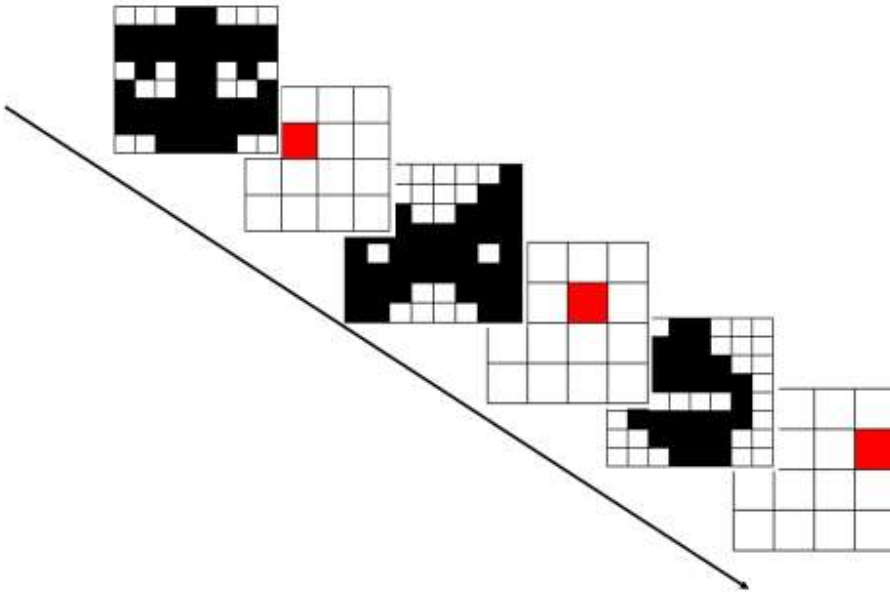


Figure 2D. A schematic depicting a trial of the Symmetry Span paradigm (set size of 3) (Unsworth, Heitz, Schrock & Engle, 2005). For this task, participants are asked to decide whether the black and white pattern is symmetrical or not symmetrical prior to being presented with a red square that randomly appears in 1 of 16 random locations. After being shown combinations of patterns and red squares, participants are asked to recall where the squares were shown to them and in the correct order they were shown to them.

Reading Span Task

Participants completed the traditional reading span task developed and provided to me by Unsworth et al. (2005). This task was structured and scored the same as the symmetry span task above except that participants were asked to remember centrally presented letters instead of matrix locations, and were asked to make speeded sentence grammaticality judgments instead of speeded symmetry judgments. Participants were shown letters one at a time and told they would be asked to recall the letters in the correct order after runs of 3, 4, 5, 6 or 7 letters. Letters were recalled by pressing the appropriate keyboard key. Participants were made aware that they were

able to enter a blank response for letters in any serial positions they did not know. Prior to each letter, participants were asked to read a sentence and judge whether it was grammatically correct or not. The sentence task was used as a distraction in order to prevent active rehearsal of the letters. Participants were told, correctly, that the sentence judgements must be correct in order to receive points for the correctly recalled letters on that run. Participants were shown a total of 12 randomly ordered runs (3 runs each of 3, 4, 5, 6 and 7 sentence judgement and letter combinations), for a total of 75 to-be-remembered letters. See Figure 2E for a sample run containing three trials. In this example, participants would need to try to remember the letter “B” and then make a speeded sentence judgment indicating that the first sentence was grammatically correct. They would then need to try to remember the letter “K” and then make a speeded judgment indicating that the second sentence was grammatically correct, followed by trying to remember the letter “R” and making a speeded judgment indicating that the third sentence was not grammatically correct. At the end of the run they would be asked to report all three letters in the correct order.

Prior to beginning experimental trials, participants first practiced the letter task alone for three runs with 2 or 3 trials each, and then the sentence task alone for approximately six trials where the sentence judgement was timed, and their response time was used to pace the participant during the test trials. They also practiced both tasks together, as in the test trials, for three runs with 2 or 3 trials each. Similar to the Symmetry Span, both partial-credit and full-credit scores were obtained from the Reading Span. Similar to the Symmetry Span, the reliable partial credit scoring was used here, but correlated strongly with full credit scoring ($r > .90$).

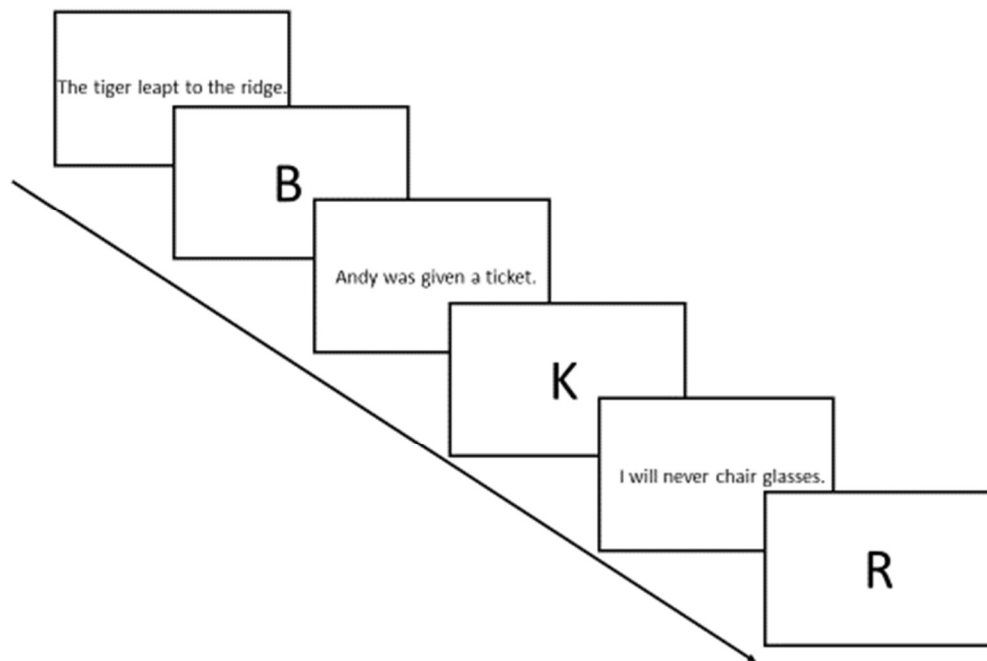


Figure 2E. A schematic depicting a trial of the Reading Span paradigm (set size of 3) (Unsworth, Heitz, Schrock & Engle, 2005). For this task, participants are asked to decide whether a presented sentence is grammatically correct or incorrect. After making their sentence judgement, participants are presented with a letter. After combinations of sentence judgements and letters, participants are asked to recall the letters that were previously presented to them as well as in the correct order the letters were presented.

Results

First I will examine the descriptive statistics for, and relationships between, the WM measures. Second, I will examine the descriptive statistics for, and relationship between, the measures of affect. Lastly, I will examine the relationship between the measures of WM and measures of affect.

Working Memory Measures

Descriptive Statistics for Working Memory Tasks

Descriptive statistics for all working memory tasks can be found in Table 1. For the Gray version of the verbal and spatial 2-back tasks, the data from four participants were not available

because of programming errors, and data from 14 participants were removed because of these participants failing to make a response for the trial prior to the presentation of the stimulus for the subsequent trial on 25% or more of the trials. The remaining 77 participants were included in the analyses. The non-Gray verbal 2-back task was introduced at participant 20. Data from 7 participants were removed because of their failure to respond on 25% or more of the trials, leaving data from 68 participants. The Non-Gray Spatial 2-back Task was added at participant 15. Data from 10 participants were removed because of their failure to respond in time on 25% or more of the trials, leaving 70 participants in the sample. Values for all 2-back tasks showed a wide range of performance across participants, reflective of good individual differences.

Block 1 and block 2 performance estimates for both the Gray and Non-Gray versions of the verbal and spatial 2-back task was calculated. In order to obtain a measure of within session test-retest reliability, performance for block 1 and block 2 were correlated. Correlations between block 1 and block 2 within the same 2-back tasks showed moderate to strong relationships ranging from $r = .59$ to $r = .81$ ($ps < .01$).

The Reading Span data for 2 participants, and Symmetry Span data for 5 participants were unavailable because of computer malfunctions, leaving 93 participants, and 90 participants respectively. Similar to the 2-back tasks, performance for both span tasks showed a wide range of performance indicative of large individual differences (see Table 1).

Table 1. Descriptive Statistics for All Working Memory Measures.

Measures	N	Mean	SD	Min	Max
GVerbal	77	61.46	22.57	7.17	95.40
GSpatial	77	65.17	22.48	8.46	100.00
NGVerbal	68	83.07	19.22	5.59	100.00
NGSpatial	70	54.77	22.43	6.85	95.00
ReadingSpan	93	53.19	13.22	6.00	74.00
SymmetrySpan	90	28.31	7.32	11.00	42.00

Note: All 2-back tasks are expressed as percentage hits minus false alarms out of all presented trials. Gray verbal 2-back task (GVerbal), and Gray spatial 2-back task (GSpatial). Non-Gray versions of 2-back tasks are denoted by NG (i.e., NGVerbal, NGSpatial). Reading Span partial credit score (ReadingSpan). For the Reading Span, 75 is the maximum score that can be achieved. Symmetry Span partial credit score (SymmetrySpan). For the Symmetry Span, 42 is the maximum score that can be achieved.

Correlations Between Working Memory Tasks

Correlations between all of the working memory measures can be found in Table 2.

There were moderate to strong significant positive correlations between all of the 2-back measures (both Gray and non-Gray versions), suggesting a common element of n-back that is not stimulus or domain specific ($r > .42, p < .01$). The two Gray tasks correlated more highly with each other than the two non-Gray tasks, which is not surprising given that the same stimuli were presented in the Gray versions (letters inside rectangles shown at various locations), whereas the non-Gray versions used letters in the verbal task and matrices in the spatial task. When examining correlations between a Gray 2-back task and a non-Gray 2-back task, there was some evidence for domain specificity in that verbal-verbal and spatial-spatial correlations were

somewhat larger than verbal-spatial correlations. The Span tasks (e.g., the Reading Span and Symmetry Span) were significantly but modestly positively correlated with each other. However, correlations between span tasks and n-back tasks were more variable (r 's = .05 to .52), showed weak evidence for domain specificity, and half of the correlations fell short of significance.

Table 2. Correlations between all measures of working memory performance.

Variable	1	2	3	4	5	6
1.GVerbal	-					
2.GSpatial	.64**	-				
3.NGVerbal	.63**	.49**	-			
4.NGSpatial	.55**	.66**	.42**	-		
5.ReadingSpan	.47**	.27*	.52**	.17	-	
6.SymmetrySpan	.27*	.12	.05	.19	.31**	-

Note: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Gray verbal 2-back task is denoted by GVerbal, and Gray spatial 2-back task is denoted by GSpatial. Non-Gray versions of 2-back tasks are denoted by NG (i.e., NGVerbal, NGSpatial). Reading Span partial credit score (ReadingSpan), Symmetry Span partial credit score (SymmetrySpan). Bolded values represent within-domain correlations (i.e. verbal with verbal or spatial with spatial), and non-bolded values represent correlations between a verbal and a spatial task. Values within the boxes represent correlations within task (i.e. 2-back with 2-back or span with span), and values outside the boxes represent correlations between a 2-back task and a span task.

Principle Components Analysis

In order to investigate the variance amongst all six working memory tasks, a principle components analysis was performed using a varimax rotation. When executed using the typical

cut-off of eigenvalues greater than 1, the analysis revealed a 2-factor solution which explained 64% of the variance in working memory performance (see Table 3). When examining the rotated component matrix, 2-back scores loaded highly on factor 1, while scores on the span tasks did not. In contrast, span performance loaded highly on Factor 2, while 2-back task scores did not, providing evidence that the WM variance is somewhat task specific. In comparison, a single-factor solution explained 47% of the variance in WM scores with all tasks loading .48 or better, thereby suggesting some general WM variance that was captured by all of the tasks.

Interestingly, when 3 factors were forced into the principle components analysis (e.g., overlooking the eigenvalue cut off of 1), the additional factor explained 14% of additional variability over the 2 factor solution. However, the pattern of factor loadings meant that the factors were not readily identifiable, and the verbal versus spatial domain was still not a factor.

Table 3. Factor Loadings for Principle Components Analysis

Variables	Components	
	1	2
GVerbal	.78	.27
GSpatial	.76	.21
NGVerbal	.76	-.06
NGSpatial	.76	.31
Reading Span	.26	.67
Symmetry Span	.05	.89

Total variance explained:

64.20%

Note: Gray verbal 2-back (GVerbal), Gray spatial 2-back (GSpatial). Non-Gray versions of 2-back tasks are denoted by NG (i.e., NGVerbal, NGSpatial).

Composite Variable Creation

Because the principle components analysis revealed a sensible 1 factor solution indicating that all the working memory tasks used here share some common variance, standardized working memory performance scores for all six tasks were averaged into a composite variable representing overall WM performance. In addition, following the 2-factor solution revealed by the principal components analysis (e.g., 2-back tasks loading highly on factor 1 and Span tasks loading highly on factor 2), a 2-back performance composite variable was created which was the average of the standardized scores for all four n-back tasks, and a Span performance composite variable was created which was the average of the standardized

scores for both Span tasks. Although not supported by the principle components analysis, prior evidence suggests affect can differentially influence verbal and spatial WM. Therefore, composite variables were also created for verbal WM (the average of the standardized scores for all three verbal tasks), and spatial WM (the average of the standardized scores for all three spatial tasks).

Affect Measures

Descriptive Statistics for Affect Measures

Descriptive statistics for the valence and activation measures from the Circumplex Affect Questionnaire (trait affect) data can be found in Table 4. Scores from the Circumplex Affect Questionnaire suggest considerable variability in self-reported trait affect indicative of individual differences. As one would expect following the Circumplex Affect model's assumption that positive and negative affect are opposite poles of a single dimension, positive and negative affect scores were significantly negatively correlated ($r = -.73, p < .001$). This supports the creation of a pleasant minus unpleasant difference score to capture this dimension in a single value. However, despite good variability in the activation and deactivation scores, activation and deactivation were not negatively correlated with each other ($r = .11, p = .30$), casting doubt on the assumption that these are opposite poles of a single dimension.

The Emotion Report Form (state affect) is scored in terms of valence, but not activation. Positive affect and negative affect measures both demonstrated a wide range of scores indicative of individual differences (see Table 5), and were significantly negatively correlated with each other ($r = -.31, p = .002$), justifying the creation of a pleasant minus unpleasant valence difference score.

Table 4. Descriptive Statistics for Trait Affect (Circumplex Affect Questionnaire)

Measures	Mean	SD	Min	Max
Trait Pleasant	3.16	.63	1.16	4.56
Trait Unpleasant	2.18	.73	1.03	3.76
Trait Valence	0.98	1.27	-2.60	3.07
Trait Activation	2.60	.36	1.63	3.39
Trait Deactivation	2.68	.37	1.82	3.64
Trait Arousal	-0.08	.48	-1.83	1.26

Note: Trait Pleasant refers to all of the pleasant items averaged together. Trait Unpleasant refers to all of the unpleasant items averaged together. Trait Valence refers to the Trait Unpleasant subtracted from Trait Pleasant, indicative of an individual's overall trait valence. Activation refers to all of the activated items averaged together. Deactivated refers to all of the deactivated items averaged together. Trait Arousal refers to Trait Deactivation subtracted from Trait Activation, indicative of an individual's overall trait arousal. All scales on the Circumplex Affect Questionnaire are scored from 1 - 5. N = 95

Table 5. Descriptive Statistics for State Affect (Emotion Report Form)

Measures	Mean	SD	Min	Max
State Pleasant	4.65	1.59	.00	7.2
State Unpleasant	1.93	1.59	.00	6.2
State Valence	2.72	2.58	-3.6	6.8

Note: State Pleasant refers to all of the pleasant items averaged together. State Unpleasant refers to all of the unpleasant items averaged together. State Valence refers to the State Unpleasant subtracted from State Pleasant, indicative of an individual's overall state valence. All scales on the Emotion Report Form are scored from 0 – 8. N = 91

Correlations Between Trait Affect and State Affect

Correlations between trait valence measures from the Circumplex Affect Questionnaire and state valence measures from the Emotion Report Form can be found in Table 6. Significant positive correlations were observed amongst congruent valence qualities for trait and state affect (e.g., pleasant trait affect with pleasant state affect), and significant negative correlations were shown for opposing valence qualities between the trait and state affect (e.g., pleasant trait affect with negative state affect). This suggests a high degree of correspondence between their typical affect and current mood state, perhaps because participants arrive in a mood state that is typical for them, or perhaps because they use their current mood state to judge their typical affect.

Table 6. Correlations Between Affect Measures

Variable	State Pleasant	State Unpleasant	State Valence
Trait Pleasant	.75**	-.43**	.73**
Trait Unpleasant	-.62**	.67**	-.79**
Trait Valence	.73**	-.60**	.82**

Note: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Trait Pleasant refers to all of the pleasant items averaged together. Trait Unpleasant refers to all of the unpleasant items averaged together. Trait Valence refers to the Trait Unpleasant subtracted from Trait Pleasant, indicative of an individual's overall trait valence. State Pleasant refers to all of the pleasant items averaged together. State Unpleasant refers to all of the unpleasant items averaged together. State Valence refers to the State Unpleasant subtracted from State Pleasant, indicative of an individual's overall state valence.

Affect and Working Memory Performance

Regression Analyses - Trait Affect and Working Memory Performance

In order to investigate the simultaneous influence of trait activation, valence, and their interaction in predicting working memory performance, multiple simultaneous regressions were performed using arousal (activation), valence, and their interaction as predictors of each of the working memory composite variables (see Tables 7a-7e). Valence and arousal scores were each standardized and then these values multiplied together to obtain the interaction term. Neither the effect of arousal, nor the interaction between arousal and valence, uniquely predicted significant variability in any working memory performance measure. With the exception of the Span task composite variable and verbal WM composite variable, valence uniquely predicted performance for all working memory composite variables (see Tables 7a-7e) where a greater preponderance

of positive relative to negative trait affect was associated with better WM performance³. Note that a preponderance of positive relative to negative affect was good for both verbal and spatial WM measures.

Table 7a. Simultaneous Regression With Trait Affect Predictors and Working Memory

Composite Variable

Predictor	β	t	P	Semi-partial r
Arousal	-.10	-.61	.55	-.82
Valence	.33	2.40	.02	.32
Interaction	.04	.23	.82	.03

Note: Criterion variable is a composite variable composed of all 6 working memory tasks.

Table 7b. Simultaneous Regression With Trait Affect Predictors and 2-back task Working

Memory Composite Variable

Predictor	β	t	p	Semi-partial r
Arousal	-.05	-.27	.79	-.04
Valence	.30	2.20	.03	.30
Interaction	-.05	-.31	.76	-.04

Note: Criterion variable is a composite score composed of all 2-back working memory tasks.

³ When Activation or Deactivation were included as predictors instead of the arousal dimension, the regressions revealed a similar pattern where valence was shown to predict WM performance over and above arousal and the interaction between valence and arousal.

Table 7c. Simultaneous Regression With Trait Affect Predictors and Span Task Working Memory Composite Variable

Predictor	β	t	p	Semi-partial r
Arousal	-.11	-.72	.48	-.08
Valence	.09	.82	.41	.09
Interaction	.17	1.11	.27	.12

Note: Criterion variable is a composite variable composed of both the Reading Span and Symmetry Span working memory tasks.

Table 7d. Simultaneous Regression With Trait Affect Predictors and Verbal Working Memory Composite Variable

Predictor	β	t	p	Semi-partial r
Arousal	-.09	-.55	.58	-.07
Valence	.24	1.82	.08	.24
Interaction	.02	.10	.92	.01

Note: Criterion variable is a composite variable composed of all 3 verbal working memory tasks.

Table 7e. Simultaneous Regression With Circumplex Affect Predictors and Spatial Working Memory Composite Variable

Predictor	β	t	p	Semi-partial r
Arousal	-.09	-.57	.57	-.07
Valence	.29	2.29	.03	.29
Interaction	.17	1.07	.29	.14

Note: Criterion variable is a composite variable composed of all 3 spatial working memory tasks.

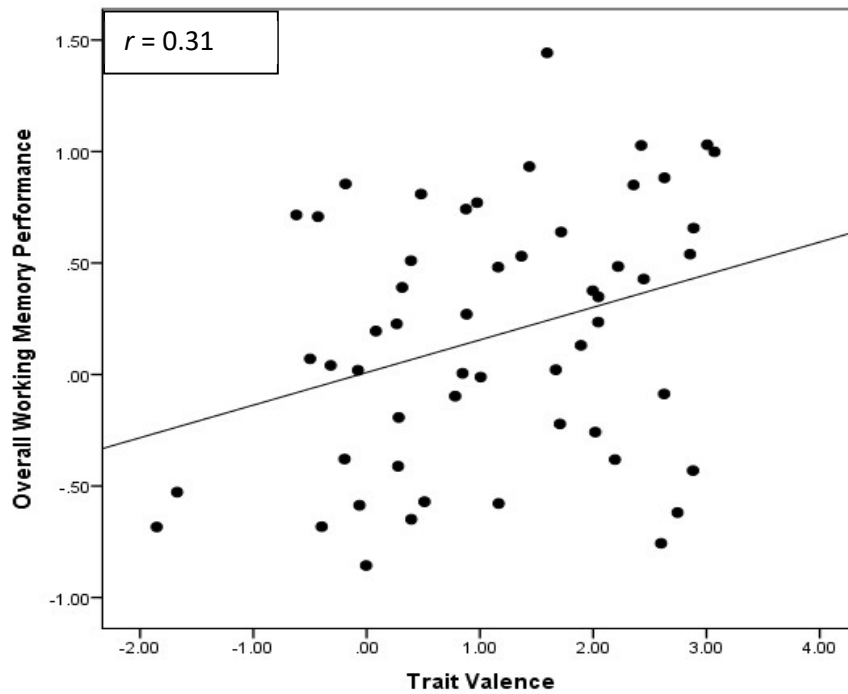
Valence and Working Memory Performance

The above regressions provide evidence that the valence dimension of trait affect predicted WM performance over and above activation and the interaction of valence and activation. Is this because positive affect was positively related to WM, because negative affect was negatively related to WM, or both? Can these relationships be found for state affect also? Correlations between trait and state valence measures and the WM composite variables)⁴ can be found in Table 8. Both trait valence and state valence were significantly positively correlated with overall WM performance (see Figure 3A and 3B). Trait and state negative affect were both significantly negatively correlated with overall WM performance (see Figures 4A and 4C), and trait and state positive affect were significantly positively correlated with overall WM performance (see Figure 4B and 4D). So, both trait and state valence scores predict WM performance in the same manner, with state valence perhaps being slightly more associated with WM performance than trait valence. In addition, both trait and state affect were shown to be a better predictor of 2-back performance than Span performance. Neither trait nor state valence predicted Span performance. Both trait and state valence were associated with better verbal and spatial WM performance where a preponderance of positive relative to negative affect was associated with better WM performance in both domains. For verbal WM, much of this was driven by negative affect which was significantly related to poorer verbal WM performance. Positive affect was not as strongly associated with verbal WM performance, although did show non-significant positive correlations. However, spatial WM performance was predicted by both

⁴ Similar patterns of associations between affect and WM performance that were shown with the composite variables were observed with the individual tasks, although noisier than with the composite variables as one would expect. See Appendix D for all zero-order correlations.

positive and negative affect where positive affect was associated with good spatial WM performance, and negative affect was associated with poor spatial WM performance.

A



B

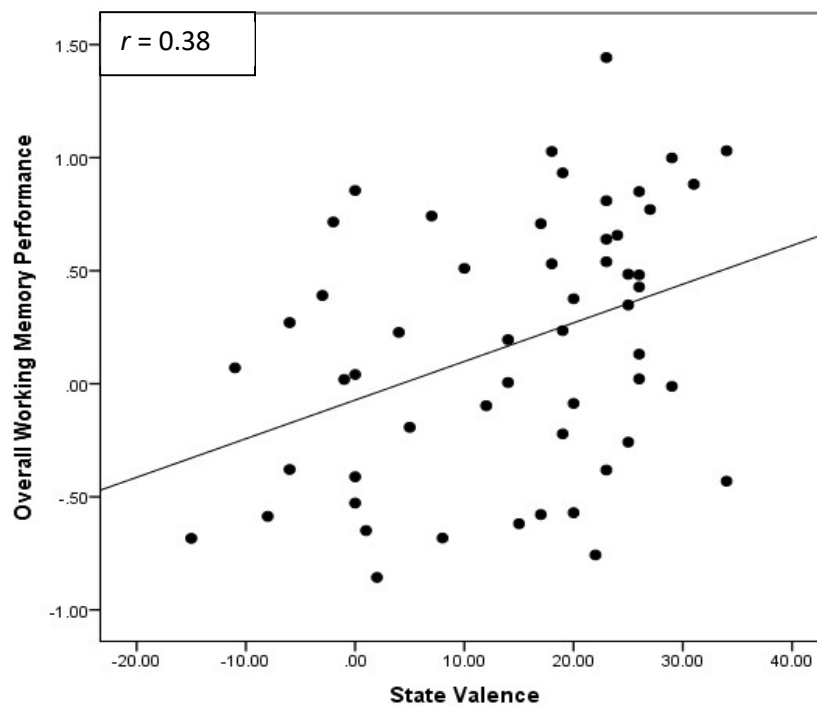
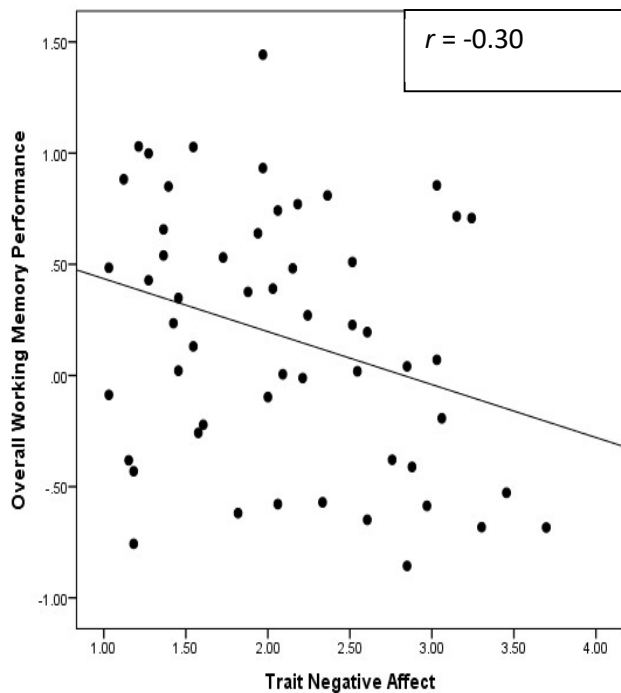
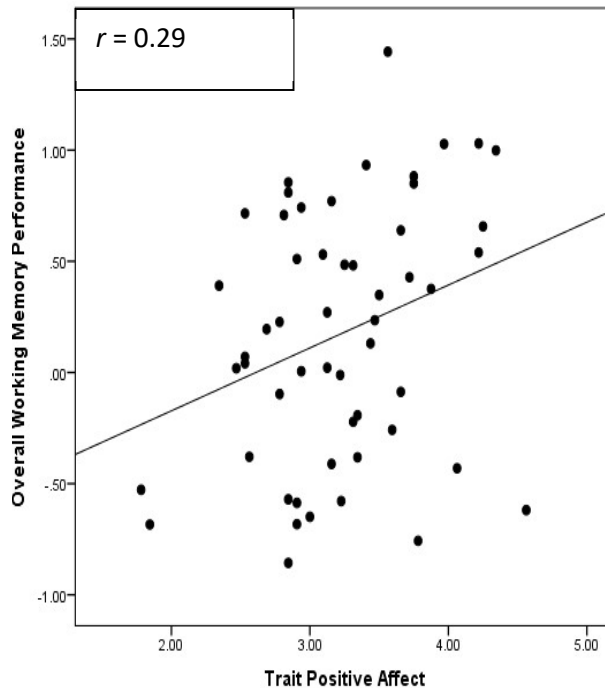


Figure 3A. A scatterplot showing the relationship between the z-scored working memory performance composite variable created from all 6 working memory measures and trait valence (Pleasant minus Unpleasant scales from the Circumplex Affect Questionnaire). *3B.* A scatterplot showing the relationship between the composite variable made from all 6 working memory measures and state valence (positive minus negative scales from the Emotion Report Form).

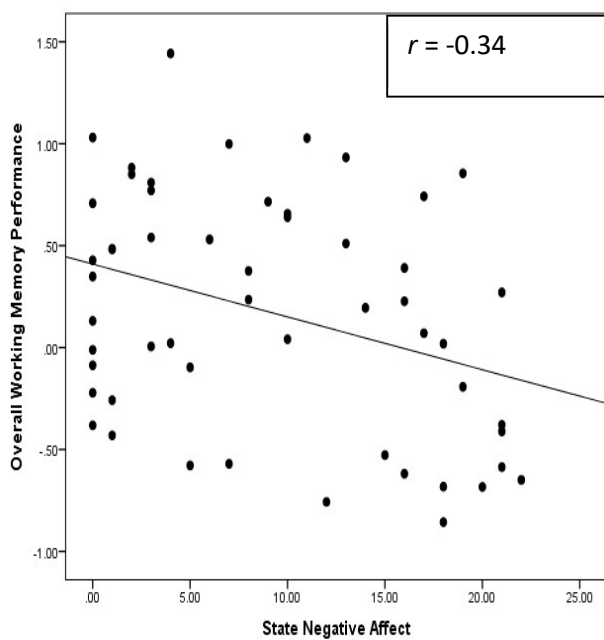
A



B



C



D

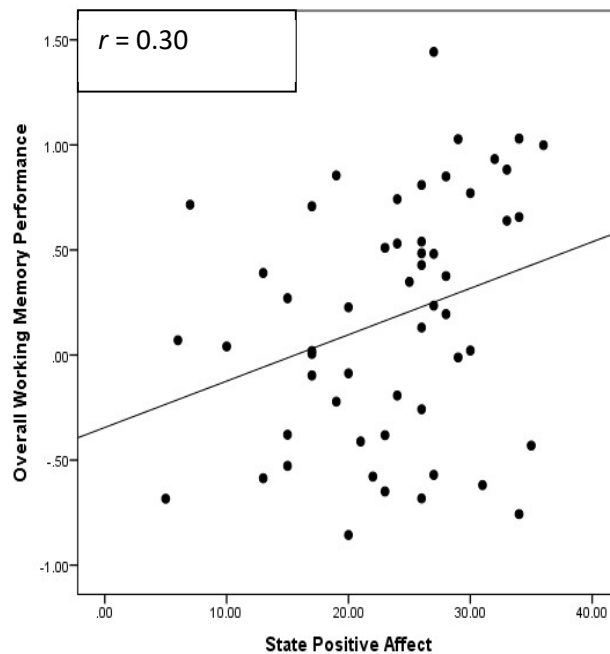


Figure 4A. A scatterplot showing the relationship between the z-scored working memory performance composite variable created from all 6 working measures and trait negative affect (the unpleasant scale from the Circumplex Affect Questionnaire). 4B. A scatterplot showing the relationship between the composite variable made from all 6 working memory measures and trait positive affect (the pleasant scale from the Circumplex Affect Questionnaire). 4C. A scatterplot showing the relationship between the z-scored working memory performance composite variable created from all 6 working measures and state negative affect (the negative scale from the Emotion Report Form). 4D. A scatterplot showing the relationship between the composite variable made from all 6 working memory measures and state positive affect (the positive scale from the Emotion Report Form).

Table 8. Correlations Between Affect Valence and Working Memory Composite Variables

Variable	WM	Two-Back	Span	Verbal WM	Spatial WM
Trait Positive	.29*	.29*	.11	.17	.32*
Trait Negative	-.30*	-.27	-.03	-.26*	-.21
Trait Valence	.31*	-.30*	.07	.23	.28*
State Positive	.30*	.26	.11	.10	.25*
State Negative	-.34*	-.28*	-.13	-.41**	-.31*
State Valence	.38**	.32*	.15	.32*	.34**

Note: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Trait Positive refers to the average of all pleasant items from the Circumplex Affect Questionnaire. Trait negative refers to the average of all unpleasant items from the Circumplex Affect Questionnaire. Trait valence refers to the pleasant average minus the unpleasant average from the Circumplex Affect Questionnaire. State positive refers to averaged positive adjective scores on the Emotion Report Form. State negative refers to averaged negative items on the Emotion Report Form. State valence refers to the positive score minus the negative score from the Emotion Report Form. Working Memory refers to the composite variable created from performance on all six working memory tasks. Two-back refers to the composite variable created from performance on all four 2-back tasks. Span Performance refers to the composite variable from performance on both span tasks. Verbal Working Memory refers to the composite variable made from performance on all three verbal working memory tasks. Spatial Working Memory refers to the composite variable made from performance on all three spatial working memory tasks.

In order to examine whether state and trait measures of valence explain the same variability in WM, or unique variability (i.e. whether one or both predict WM over and above the other), both trait and state valence variables were entered into a simultaneous regression as predictors, with overall WM performance as the criterion variable. Both trait and state valence combined explain a significant 14% of variability in overall WM performance $F(2,51) = 4.19, p$

= 0.02, $R = .38$. In addition, trait valence was shown to explain almost no variability in WM performance over and above state valence. State valence did account for some variability in WM over and above trait affect valence, but this was not significant, suggesting that trait and state affect explain the same variability in WM, with state explaining a non-significant amount of additional variability⁵ (see Table 9).

Table 9. Simultaneous Regression with Affect as Predictors and the overall Working Memory Performance Composite Variable

Predictor	β	t	p	Semi-partial r
Trait Valence	.03	.14	.89	.02
State Valence	.35	1.59	.12	.21

Note: Criterion variable is a composite variable composed from all 6 working memory tasks.

Arousal, Valence and Working Memory Performance

As supported by the simultaneous regressions, arousal (i.e., activation, deactivation, and the arousal dimension), were not significantly associated with WM performance (see Table 10). Furthermore, in contrast to patterns shown by affect valence and WM performance, no clear or sensible patterns were observed, indicative of the lack of association between trait arousal and WM performance.

⁵ Simultaneous Regressions were similarly performed for each of the WM composite variables. A similar pattern was shown where neither trait or state valence uniquely predicted variability in WM performance over and above one another.

Table 10. Correlations Between Trait Arousal and Working Memory Composite Variables

Variable	WM	Two-Back	Span	Verbal WM	Spatial WM
Activation	-.11	-.06	.04	-.17	.04
Deactivation	-.04	.01	.02	-.08	-.01
Arousal	-.05	-.05	.02	-.06	.04

Note: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Trait Activation refers to the averaged activated item scores from the Circumplex Affect Questionnaire. Trait Deactivation refers to the averaged deactivated item scores from the Circumplex Affect Questionnaire. Trait Arousal refers to the deactivation score minus the activation score from the Circumplex Affect Questionnaire. Working Memory refers to the composite variable created from performance on all six working memory tasks. Two-back refers to the composite variable created from performance on all four 2-back tasks. Span Performance refers to the composite variable from performance on both span tasks. Verbal Working Memory refers to the composite variable made from performance on all three verbal working memory tasks. Spatial Working Memory refers to the composite variable made from performance on all three spatial working memory tasks.

The correlations in Table 8, combined with the lack of interaction effects in the regressions, suggest that both activated and deactivated positive states should be positively related to WM performance, whereas both activated and deactivated negative states should be negatively related to WM performance. Each of the four combinations of positive/negative affect and low/high activation were correlated with WM composite variables and these are shown in Table 11. For trait affect, the positive and negative activated states appear to show slightly larger relationships with WM than the positive and negative deactivated states, but consistent with the lack of interactions in the regressions, the pattern of valence relationships is the same for both activated and deactivated states, where greater positive affect predicts higher WM performance and negative affect predicts lower WM, at least overall and in 2-back tasks. For state affect, the activated and deactivated states appear to show equally strong relationships between valence and

WM where greater positive affect again predicts higher WM performance and negative affect predicts lower WM, with the exception of Span task performance.

Table 11. Correlations between Affect Measures and Composite Variables

Variable	Working Memory	Two- Back	Span Performance	Verbal Working Memory	Spatial Working Memory
Trait PA	.27*	.29*	.09	.13	.30*
Trait PD	.19	.20	.06	.16	.21
Trait UA	-.31*	-.28*	-.04	-.28*	-.19
Trait UD	-.18	-.14	.00	-.18	-.15
State PA	.25	.26	.03	.08	.18
State PD	.28*	.19	.19	.11	.30*
State UA	-.28*	-.23	-.11	-.39**	-.23
State UD	-.40**	-.33*	-.16	-.34*	-.43**

Note: **Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2- tailed). Pleasant Activated (PA), Pleasant Deactivated (PD), Unpleasant Activated (UA), Unpleasant Deactivated (UD). Working Memory refers to the composite variable created from performance on all 6 working memory tasks. Two-back refers to the composite variable created from performance on all four 2-back tasks. Span Performance refers to the composite variable from performance on both span tasks. Verbal Working Memory refers to the composite variable made from performance on all three verbal working memory tasks. Spatial Working Memory refers to the composite variable made from performance on all three spatial working memory tasks.

General Discussion

The current study investigated whether naturally occurring affect could predict WM performance on tasks that vary in domain (i.e., verbal/spatial), and task type (i.e., complex span and n-back). The present results demonstrate that in the absence of induced mood states, individual differences in affect can predict individual differences in WM performance. When WM was calculated using all six tasks, averaging across task type (i.e., n-back or span), and stimulus domain (i.e., verbal or spatial), both self-reported trait and state affect valence were shown to predict WM performance over and above arousal and the interaction between valence and arousal. A clear pattern was observed where positive affect was associated with better WM performance and negative affect was associated with poorer WM performance. This same pattern was observed for both verbal and spatial WM tasks. However, while this pattern was observed: 1) overall across the six WM tasks, 2) for both verbal and spatial tasks, and 3) for n-back tasks, the correlations between affect and WM performance on the Span tasks were not significant, although they did follow the same directional pattern. The current findings demonstrate that independent of WM domain (i.e., verbal or spatial), positive affect predicts better WM performance and negative affect predicts worse WM performance.

Trait and state valence were shown to individually predict overall WM performance. However, neither trait or state affect valence were shown to predict WM performance individually over and above one another. This finding is not surprising because of the strong association observed here between an individual's current mood and an individual's general day-to-day mood (see Table 10). This finding also suggests that participants are completing the task in a mood state that is similar to the mood state that they are generally in from day-to-day, and

that relationships with trait affect may be driven through participant's current state as they perform the task.

The Influence of Valence Across Task Type

This domain general influence of affect valence on WM provides support for existing theories that explain affect and WM interactions through mechanisms of executive control (e.g., Vytal et al., 2013; Storback and Maswood, 2016). Using a negative mood induction paradigm (i.e., shock threat), Vytal et al., (2013) showed that highly negative withdrawal states were detrimental for spatial 1,2 and 3-back performance, and for verbal 1 and 2-back performance, compared to neutral states with no shock threat. Furthermore, individuals who showed greater startle responses and reported more anxiety in response to the shock threat showed the most impairment in WM with shock threat. Therefore, the present results provide converging evidence to those of Vytal et al., (2013) by showing reduced verbal and spatial 2-back performance with higher negative affect, and significant correlations between state affect and WM performance. The current results extend the findings of Vytal et al. by demonstrating that even relatively low levels of naturally occurring trait and state negative affect are associated with lower overall working memory performance. Although shock threat disrupted verbal and spatial 1 and 2-back performance, spatial, but not verbal, 3-back performance was affected by shock threat in Vytal et al. (2013). Vytal and colleagues explained their findings in terms of the Two Component Model of Anxiety that states that anxiety has two mechanisms by which cognition is affected (Vytal et al., 2012). The first component, threat preparation, is said to increase physiological arousal to facilitate spatial awareness and threat management, and this is thought to overlap with neural circuitry involved in spatial WM. The second component, anxious apprehension, such as rumination and worry, is said to disrupt rehearsal processes associated with language processing,

and is thought to overlap with the neural circuitry involved in verbal WM. Vytal et al. (2013) postulated that anxious worry is reduced under increasingly difficult task demands, which removes the cost of threat for 3-back verbal trials, but physiological arousal remains high in 3-back spatial trials so the effect is unchanged for the 3-back spatial trials. Therefore, even though Vytal et al. (2013) showed that shock threat impaired verbal and spatial 1 and 2-back performance, to account for different effect of threat for verbal and spatial WM at 3-back, they argued that different neural mechanisms were responsible for the verbal and spatial WM impairments under threat. Notice that while this theory can explain how negative affect impairs WM performance, it cannot easily explain the association between positive affect and WM observed here.

Storbeck and Maswood (2016) showed that induced positive mood (i.e., via an amusement video), facilitated performance on both verbal and spatial complex span tasks, but that a sadness-inducing video had no effect on verbal and spatial complex span performance relative to an emotionally neutral induction condition. They also showed that participants' self-reported state valence (after the mood induction) predicted both verbal and spatial span scores where more positive moods predicted better verbal and spatial WM performance. Self-reported arousal rating (after the mood induction) did not predict either verbal or spatial span scores. Finding that positive affect was beneficial for both verbal and spatial span tasks was particularly impressive given that verbal/spatial was manipulated between participants in their study so carryover effects across WM tasks were not possible. The results from the current study are consistent with those of Storbeck and Maswood (2016) in that at both high and low levels of arousal, naturally occurring positive affect was associated with better overall WM performance. In the present study this pattern was also observed for Span tasks alone, but these effects fell well

short of significance. However, the present finding that negative affect was associated with reduced WM performance, was not observed in Storbeck and Maswood (2016), perhaps attributable to the atypical sad mood induction, compared to more typical anxious mood inductions used by Gray and colleagues (e.g., Gray, 2001; Gray et al., 2002). The present results also extend those of Storbeck and Maswood (2013) by showing that the domain-general benefit of positive affect can be observed with naturally-occurring (as opposed to induced) affect, and can also extend to n-back tasks.

Storbeck and Maswood (2016) explained their modality independent influence of positive affect in terms of the Broaden and Build Theory of positive emotions where positive emotions are stated to build psychological resources (Fredrickson, 2001). According to Storbeck and colleagues, positive affect facilitates performance on their verbal and spatial complex span tasks by building psychological resources that are devoted to higher-order executive control processes. Individuals who are generally in a more positive mood may have more psychological resources in order to manage relevant information (i.e., the presented letters in the reading span task) and filter out irrelevant information (i.e., the grammatical sentence judgements), compared to those who are generally in a negative mood. These findings would be consistent with Vytal et al. (2013) who showed that anxiety impaired WM performance, perhaps by consuming resources that should be devoted to executive control processes. Recall that several researchers have used n-back tasks to show that verbal WM is facilitated by positive/approach emotions but spatial WM is facilitated by negative/withdrawal emotions. Storbeck and Maswood argue that Span tasks may require more executive control than n-back tasks, so if positive affect facilitates executive control, then this could supersede any domain specific effects observed in tasks with

fewer executive control demands. However, that would not explain the present results where positive affect was shown to predict better WM performance overall and on n-back tasks.

The pattern reported here where positive affect is associated with better WM performance, and negative affect is associated with worse WM performance is also consistent with previous results showing that self-reported naturally occurring affect can predict other cognitive performance measures such as attentional breadth (e.g., Arnell et al. submitted), the attentional blink (MacLean et al., 2010; MacLean et al., 2010), and flexible and inclusive thinking (Arnell et al, submitted; Middlewood et al., 2016).

In contrast to the current findings, Gray and others (e.g., Gray, 2001; Gray et al. 2002; Storbeck, 2016) have demonstrated that approach positive affect (amusement) benefits verbal WM 2-back performance and impairs spatial 2-back WM performance, and that negative withdrawal affect (anxiety) benefits spatial 2-back performance and impairs verbal 2-back performance. These findings were explained by Gray in terms of hemispheric differences between affect (i.e., approach and withdrawal states), and WM domain (i.e., verbal and spatial) in the left and right hemisphere, respectively. More specifically, with positive approach affect and verbal information predominately depending on left hemisphere activity, approach affect was said to facilitate performance on verbal WM tasks by prioritizing the left hemisphere for goal-oriented behaviour. Similarly, negative withdrawal states and spatial WM tasks are both predominately dependent on the right hemisphere, so withdrawal affect was said to facilitate performance on spatial WM tasks by prioritizing the right hemisphere.

In addition, Storbeck (2016) replicated a pattern of results similar to Gray (2001), where participants performed better on a verbal 2-back following a positive mood induction (i.e., amusement), compared to the negative mood induction (i.e., sadness), but the reverse pattern was

observed for spatial 2-back tasks. Unlike Gray (2001), participants completed the incongruent Stroop Task to induce a psychological challenge just prior to the mood induction and performing the WM tasks, showing that this pattern can be observed even after exerting self-control. Interestingly, in a different study, Storbeck (2012) showed that when participants performed an n-back task in a mood state compatible with the stimulus (i.e., positive approach and verbal or negative withdrawal and spatial), performance on a subsequent self-control task was better than when participants performed the n-back task in a mood state incompatible with the stimulus (i.e., positive approach and spatial or negative withdrawal and verbal). Storbeck (2016) explained these findings in terms of Emotion Goal Compatibility Theory which states that our emotions automatically prioritize aspects of behaviour that are congruent with accomplishing the perceived goal. For example, positive emotions are stated to prioritize processing that is congruent with language and social engagement. In contrast, negative affect is stated to prioritize goals that are congruent with managing threatening situations and spatial awareness (Storbeck, 2016). If the WM stimulus and mood state are congruent then WM performance is enhanced and accomplished with less effortful self-control, whereas if the WM stimulus and mood state are incongruent then WM performance is impaired and requires more effortful self-control that can become depleted.

The present findings suggest a more domain independent influence of affect on WM performance. Gray and Storbeck would have predicted the pattern found here for verbal tasks (i.e., more positive affect being associated with better verbal WM performance, and more negative affect being associated with worse verbal memory performance). Indeed, Gray (2001) observed that high arousal negative affect (fear) was bad for verbal WM, and Storbeck (2016) observed that low arousal negative affect (sadness) was bad for verbal WM, and the present

study showed that both low and high arousal negative affect (UA and UD, see Table 9) were associated with worse verbal WM performance. However, opposite to what would have been predicted by Gray and Storbeck, the present results demonstrate that positive affect was also positively associated with spatial WM and negative affect was negatively associated with spatial WM (i.e., the spatial working memory composite variable). These findings could potentially be explained by naturally occurring affective states not being high enough in motivation in the present study. Gray and colleagues explained their results in terms of the hemispheres being primed by the affective state to facilitate processing of WM stimuli associated with that hemisphere (e.g., positive approach priming the left hemisphere to facilitate verbal WM performance). Perhaps the inconsistency with the current results are a result of dispositional affective states not priming hemispheric activation, but instead modulating executive control processes more generally. Some evidence for this idea comes from the finding that left hemisphere activation of high approach individuals increased after self-control when viewing positive pictures, but not when viewing neutral pictures, suggesting that approach-related stimuli may be needed to activate left hemisphere approach affects (Schmeichel Crowell and Harmon-Jones (2016), and that the positive induction stimuli may have served this role in Gray's studies.

The role of approach motivation versus positive affect is also currently unclear in the WM literature. Previous literature has investigated how affect influences WM by inducing an affective state using emotional videos. For example, Gray (2001) investigated the effect of approach/withdrawal affect on WM performance. To induce an approach state, Gray used an amusement video of a stand-up comedy routine, which is clearly positive in nature, but does not seem to be particularly high in approach motivation. Recent studies examining emotion and attentional breadth have suggested that the amused state induced by comedy videos is relatively

low in approach motivation relative to states such as desire which can be induced by showing delicious desserts (e.g., Gable & Harmon Jones, 2008, 2010). Indeed, desire inductions have been shown to have a large and robust ability to reduce attentional breadth (eye on the prize) which can be amplified by increasing situational or dispositional approach tendencies (Gable & Harmon-Jones, 2008). Therefore, it is possible that Gray was investigating how positive and negative affect influence WM performance, instead of the influence of approach/withdrawal affect on WM performance. Indeed, Storbeck (2016) recently replicated the results pattern found by Gray (2001) by inducing participants into a sad, happy (stand-up comedy), or neutral moods which are all relatively low in motivational intensity states. However, if Gray (2001; Gray et al., 2002) and Storbeck (2016) did manipulate valence more so than approach/avoidance, this cannot explain the different pattern of results in the current study and their studies. If, however, Gray (2001) and Storbeck (2016) were indeed measuring motivationally driven effects of affect on WM, then the different pattern of results in the current study and their studies could possibly be attributed to the current study tapping into valence compared to motivational aspects of affect.

Inconsistencies were also observed when examining the relationship between affect and span performance. Storbeck and Maswood (2016) found that induced positive affect resulted in better verbal and spatial span performance than induced neutral or negative affect which did not differ from each other. Furthermore, the more positive participants reported their mood to be after the inductions, the better their WM performance. However, in the present study the composite variable made from overall Span task performance (i.e., Reading Span and Symmetry Span), was not significantly predicted by affect, nor were Reading Span or Spatial Span scores separately. However, although the relationships were small and non-significant, affect was shown to be related to span performance in a similar direction to the other WM composite

variables in the present study. It seems likely that the positive mood induction used by Storbeck and Maswood (2016) resulted in a stronger positive mood than the naturally-occurring positive mood experienced by participants in the present study, and this may have increased the size of their effects relative to those observed here.

Indeed, there were differences in the strength of association between affect valence and the WM tasks where affect was most weakly associated with the Span tasks, and more strongly associated with the centrally presented 2-back tasks compared to the 2-back tasks used by Gray (2001). The difference among n-back tasks could potentially be because of the centrally presented 2-back tasks being more distinct in modality (use of letters only versus matrix locations only) compared to the Gray (2001) version of the 2-back where letters always appeared in various locations. For example, having to switch and subsequently maintain different 2-back instructions (i.e., the switch between the letter being important compared to the location being important), could potentially involve different mechanisms associated with maintenance and filtering compared to changing the stimuli.

The present results suggest that affect may modulate n-back performance more strongly than span performance. Interestingly, supporting the distinction posited between complex span tasks and n-back tasks shown by Redick et al., (2013), the principle components analysis was sensibly divided into a 2 factor solution with n-back tasks loading highly on factor 1 and span tasks loading highly on factor 2. As evidenced by imaging studies discussed in the Introduction, differences in medial temporal recruitment have been shown where complex span tasks require more recruitment compared to n-back tasks (Redick et al., 2013; Chien et al., 2011; Faraco et al., 2011). This suggests that different mechanisms are associated with the active updating of

important information (i.e., n-back) and actively encoding, maintaining, and retrieving information in the face of interference from irrelevant information (i.e., complex Span tasks).

There was little to no evidence for domain (verbal/spatial) specific variance. Correlations between tasks within a domain were almost as high as correlations between tasks across domain. Also, when 3 or 4 factor solutions were forced in a principle components analysis, the additional factor(s) did not represent verbal/spatial particularly well. This could potentially explain the inconsistent results between the current study, where good verbal and spatial WM performance showed the same pattern of relationships with affect, and several previous findings where affective states differentially affect verbal and spatial n-back performance (e.g., Gray, 2016; Gray et al., 2002; Storbeck, 2016). Because each of the participants in the present study performed both verbal and spatial versions of each task, it was possible to examine correlations within and between domain, making it easy to observe little evidence for domain specificity in the current WM data. However, verbal versus spatial tasks were manipulated between participants in Gray (2001) and Storbeck (2016), making such analyses impossible. Gray et al., (2002) and Vytal et al. (2013) manipulated verbal and spatial n-back tasks within participants, but did not report correlations amongst the two versions, making it impossible to compare the amount of domain specific variability in the present study and theirs. Therefore, it is possible that the verbal and spatial WM tasks used here share more variability than those of Gray (2001, Gray et al., 2002) and Storbeck (2016). However, this seems unlikely as the Gray tasks used here were modelled exactly on those of Gray (2001, Gray et al., 2002), and if anything, the non-Gray n-back tasks were more effective in removing any verbal coding from the spatial task and any spatial coding from the verbal task given that the letters were presented in a single location for the verbal task, and only locations of non-verbal matrix locations varied in the spatial task.

Potential Neurophysiological Explanations

The present findings suggest that independent of stimulus domain and task type, positive valence was associated with better WM performance while negative valence was associated with poorer WM performance. However, as previously shown, several inconsistencies were observed between the results of the current study and past literature. Storbeck and Maswood (2016) posited that their results showing improved verbal and spatial WM span performance after induced positive mood can be explained through the role of dopamine when completing tasks that require executive control. Dopamine has been posited to facilitate cognitive processes that are related to WM such as problem solving (Ashby et al., 1999). It is possible that those who are generally in a more positive mood have more dopamine to facilitate goal relevant behaviour compared to those in a negative mood who would have the least. As previously discussed in the Introduction, extensive imaging work has shown that there are dissociable areas that are involved in performing span tasks, compared to n-back tasks (e.g., the medial temporal area and frontal/parietal areas respectively). These areas could potentially be affected differentially by affect valence and arousal. For example, LaBar and Phelps (1998) have shown that arousal plays a critical role in memory consolidation through its affect on temporal/frontal neural circuitry. This effect of arousal on temporal areas may be undermined in the current study which showed no evidence for a bipolar arousal dimension in that some participants reported themselves as being both generally activated (e.g., anxious and nervous), as well as deactivated (e.g., tired and bored), and this could explain part of the difficulty in predicting span performance which relies on such areas. Complex span tasks are posited to rely on mechanisms associated with long term memory consolidation and retrieval (Faraco et al., 2011). In line with LaBar et al., (1998), our current results show that complex span performance is less associated with valence compared to

the 2-back tasks and the valence dimension proved valid as participants who identified themselves as experiencing positive valence, did not similarly identify themselves as experiencing negative valence. It is possible that in the current study, the connection between parietal areas and the PFC are more susceptible to the influence of affect valence compared to the temporal/frontal connections required by complex span tasks. Naturally occurring positive affect may lead to better WM performance compared to negative affect as result of dopamine interactions with parietal areas and the PFC. Temporal/frontal connections may require higher arousal (e.g., via induced mood), in order have an impact on complex span performance.

Limitations, Strengths, and Future Directions

A limitation of the current study is that the principle components analysis did not divide the WM variability sensibly based on stimulus domain. Without much domain specific variability, it is difficult to accurately investigate separable variability in verbal and spatial WM that could potentially be related to affect in different ways. Therefore, the lack of different effects of emotion on verbal and spatial WM could be potentially be attributed to the stimuli lack of domain specific WM variability in the current study.

The current study uses the circumplex affect questionnaire to obtain self-reported measures of trait affect. The present findings showed a large negative correlation between positive and negative valence, as the Circumplex Affect model would predict, but did not show any negative relationship between activated and deactivated states (e.g., some participants reported to be both activated and deactivated). This suggests that, at least for the present study, activated/deactivated did not create a bipolar dimension as predicted by the Circumplex Affect model. This could potentially be responsible for why the arousal dimension was not successful at predicting WM performance. Anecdotally, it appeared that participants often reported feeling

tired (a low activation emotion) even as they also reported higher arousal mood states such as anxiety or happiness.

The current study is also limited by not having any measures of motivational intensity *per se* (e.g., asking participants how much they wanted to approach or withdraw during the task). Previous research has demonstrated that highly motivationally intense approach and withdrawal states narrow cognitive scope (Gable & Harmon-Jones, 2008; 2010). Gray (2001) argued that the amusement video increased verbal WM and decreased spatial WM performance because of its approach tendencies more than the positivity *per se*, and that the fear video decreased verbal WM and increased spatial WM performance attributable to its withdrawal tendencies more than the negativity *per se*. It is possible that the results here differ from those of Gray because Gray manipulated both approach and positive affect with his amusement video, and both withdrawal and negative affect with his fear video, whereas positive and negative was measured here instead of motivational intensity *per se*.

Future studies should investigate dispositional affect and other WM tasks that involve different task demands (i.e., forms of interference) and stimulus characteristic (e.g., different non-verbal stimuli). Indeed, previous studies that demonstrated the modality specific influence of different induced affective states have used tasks that involve different forms of interference compared to the complex span tasks in the current study (i.e., math problem interference compared to grammatical judgements). Given that separable mechanisms have been identified for managing verbal and non-verbal information, how individuals keep the information in a usable form prior to responding may play a critical role in the extent to which interference impairs maintenance of relevant information. For example, in Storbeck and Maswood (2016) participants completing the spatial complex span task were asked to make their responses via

keyboard letter input (e.g., r for upper left, t for upper middle etc.). This method of response could potentially facilitate a different form of information management (e.g., more verbal recoding) compared to the current methodology where participants used a computer mouse to click on the matrix locations.

Future studies should attempt to use these same tasks after inducing mood states with both high and low levels of approach and withdrawal motivational intensity (e.g., low approach positive such as serene, and high approach positive such as desire, low withdrawal negative such as sadness, and high withdrawal negative such as fear). In contrast to the current study, this would allow a clearer examination of the motivational intensity effect and whether or not it interacts with valence. It would also allow cause and effect explanations to be made when interpreting specific findings in regards to the influence of affect on verbal and spatial WM performance.

A strength of the current study is that it is the first to investigate the role of naturally occurring affect on WM performance. An individual is less likely to be in situations that resemble induced mood in their everyday lives, relative to their typical emotional state. Therefore, the present findings suggest that naturally occurring affect could have a role in shaping WM performance daily across a variety of cognitive activities. These findings also demonstrate that even at the lower levels of typical affect, an individual's ability to process and manage information is impacted.

Conclusion

The present findings suggest a valence driven association between naturally-occurring affect and WM performance. Contrary to previous literature demonstrating specific effects of induced

positive/approach and negative/withdrawal affective states on verbal and spatial WM performance (e.g., Gray, 2001; Gray et al., 2002; Storbeck, 2016), the present results demonstrate that independent of stimulus domain, positive affect is associated with better WM performance while negative affect is associated with lower WM performance. These findings are consistent with those of Storbeck and Maswood (2016) where induced positive affect was good for WM performance across both verbal and spatial stimulus domains. I posit that both naturally occurring moods and induced moods influence WM performance through the same mechanism which is associated with directing one's attention to goal relevant cognitive processes.

References

- Alvarez, G. A., & Cavanagh, P. (2004). The Capacity of Visual Short-Term Memory Is Set Both by Visual Information Load and by Number of Objects The Capacity of Visual Short-Term Memory Is Set Both by. *Psychological Science*, *15*(2), 106-111.
- Arnell, K., Chung, A., Dale, G., & MacLean, M. (*under revision*). Dispositional affect predicts attentional and conceptual breadth: Individual difference evidence for the importance of arousal and valence interactions. *Emotion*.
- Ashby, F. G., Isen, A. M., & Turken, A. U. (1999). A Neuropsychological Theory of Positive Affect and Its Influence on Cognition. *Psychological Review*, *106*(3), 529–550.
- Awh, E., & Jonides, J. (2001). Overlapping mechanisms of attention and spatial working memory. *Trends in Cognitive Sciences*, *5*(3), 119–126. [https://doi.org/10.1016/S1364-6613\(00\)01593-X](https://doi.org/10.1016/S1364-6613(00)01593-X)
- Awh, E., Jonides, J., Reuter-Lorenz, P. A., & Renter-Lorenz, P. A. (1998). Rehearsal in Spatial Working Memory, *Journal of Experimental Psychology*, *24*(3), 780–790.
- Awh, E., Jonides, J., Smith, E. E., Buxton, R. B., Frank, L. R., Love, T., Gmeindl, L. (1999). Rehearsal in Spatial Working Memory: Evidence from Neuroimaging Evidence From Neuroimaging. *Source: Psychological Science*, *10*(5), 433–437.
- Awh, E., Vogel, E. K., & Oh, S.H. (2006). Interactions Between Attention And Working Memory. *Neuroscience*, *139*(1), 201-208.
<https://doi.org/10.1016/j.neuroscience.2005.08.023>

- Baddeley, A. (2012). Working Memory: Theories, Models, and Controversies. *Annual Review of Psychology*, 63(1), 1–29. <https://doi.org/10.1146/annurev-psych-120710-100422>
- Carpenter, Patricia, A., Miyake, Akira, & Just. (1995). Language comprehension: Sentence and discourse processing. *Marcel Adam Annual Review of Psychology Nursing & Allied Health Database* 46(1), 91-120.
- Carver, C. S., & White, T. L. (1994). Behavioral Inhibition, Behavioral Activation, and Affective Responses to Impending Reward and Punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology*, 67(2), 319–333.
- Chein, J. M., Moore, A. B., & Conway, A. R. A. (2010). Domain-general mechanisms of complex working memory span. *Neuroimage*, 54(1), 550-559
<https://doi.org/10.1016/j.neuroimage.2010.07.067>
- Christophel, T. B., Klink, P. C., Spitzer, B., Roelfsema, P. R., & Haynes, J.-D. (2017). The Distributed Nature of Working Memory. *Trends in Cognitive Sciences*, 21(2), 111–124.
<https://doi.org/10.1016/J.TICS.2016.12.007>
- Coan, J. A., & Allen, J. J. B. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, 67, 7–49. <https://doi.org/10.1016/j.biopsycho.2004.03.002>
- Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user’s guide. *Psychonomic Bulletin & Review*, 12(5), 769–786. <https://doi.org/10.3758/BF03196772>

- Courtney, S. M., Petit, L., Maisog, J. M., Ungerleider, L. G., & Haxby, J. V. (1998.). An Area Specialized for Spatial Working Memory in Human Frontal Cortex. *Source: Science, New Series, 279*(5355), 1347–1351.
- Courtney, S. M., Ungerleider, L. G., Keil, K., & Haxby, J. V. (1996). Object and Spatial Visual Working Memory Activate Separate Neural Systems in Human Cortex. *Cerebral Cortex, 6*(1), 39–49. <https://doi.org/10.1093/cercor/6.1.39>
- Curtis, C. E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. *TRENDS in Cognitive Sciences, 7*(9), 415-423.
[https://doi.org/10.1016/S1364-6613\(03\)00197-9](https://doi.org/10.1016/S1364-6613(03)00197-9)
- D'Esposito, M., & Postle, B. R. (2015). The Cognitive Neuroscience of Working Memory. *Annu. Rev. Psychol, 66*, 115–42. <https://doi.org/10.1146/annurev-psych-010814-015031>
- D'Esposito, M., Postle, B. R., Ballard, D., & Lease, J. (1999). Maintenance versus Manipulation of Information Held in Working Memory: An Event-Related fMRI Study. *Brain and Cognition, 41*, 66–86.
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450–466.
[https://doi.org/10.1016/S0022-5371\(80\)90312-6](https://doi.org/10.1016/S0022-5371(80)90312-6)
- De Pascalis, V., Cozzuto, G., Caprara, G. V., & Alessandri, G. (2013). Relations among EEG-alpha asymmetry, BIS/BAS, and dispositional optimism. *Biological Psychology, 94*, 198–209. <https://doi.org/10.1016/j.biopsycho.2013.05.016>

- Düsing, R., Tops, M., Radtke, E. L., Kuhl, J., & Quirin, M. (2016). Relative frontal brain asymmetry and cortisol release after social stress: The role of action orientation. *Biological Psychology, 115*, 86–93. <https://doi.org/10.1016/j.biopsycho.2016.01.012>
- Ekman, P., Friesen, W. V., & Ancoli, S. (1980). Facial Signs of Emotional Experience. *Journal of Personality and Social Psychology, 39*(6), 1125–1134.
- Engle, R. W., Laughlin, J. E., Tuholski, S. W., & Conway, A. R. A. (1999). Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent-Variable Approach. *Journal of Experimental Psychology: General, 128*(3), 309–331.
- Faraco, C. C., Unsworth, N., Langley, J., Terry, D., Li, K., Zhang, D., Miller, L. S. (2011). Complex span tasks and hippocampal recruitment during working memory. *NeuroImage, 55*, 773–787. <https://doi.org/10.1016/j.neuroimage.2010.12.033>
- Fecteau, S., Knoch, D., Fregni, F., Sultani, N., Boggio, P., & Pascual-Leone, A. (2007). Behavioral/Systems/Cognitive Diminishing Risk-Taking Behavior by Modulating Activity in the Prefrontal Cortex: A Direct Current Stimulation Study. *The Journal of Neuroscience, 27*(46), 12500–12505. <https://doi.org/10.1523/JNEUROSCI.3283-07.2007>
- Feldman Barrett, L., & Russell, J. A. (1998). Independence and Bipolarity in the Structure of Current Affect. *Journal of Personality and Social Psychology, 74*(4), 967–984.
- Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist, 56*(3), 218–226. <https://doi.org/10.1037/0003-066X.56.3.218>

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition and Emotion*, 19(3), 313-332.

<https://doi.org/10.1080/02699930441000238>

Gable, P., & Harmon-Jones, E. (2010). The motivational dimensional model of affect:

Implications for breadth of attention, memory, and cognitive categorisation. *Cognition and*

Emotion, 24(2), 322-337. <https://doi.org/10.1080/02699930903378305>

Gable, P. A., & Harmon-Jones, E. (2008). Approach-Motivated Positive Affect Reduces Breadth of Attention. *Psychological Science*, 19(5), 476–482. [https://doi.org/10.1111/j.1467-](https://doi.org/10.1111/j.1467-9280.2008.02112.x)

[9280.2008.02112.x](https://doi.org/10.1111/j.1467-9280.2008.02112.x)

Gevins, A., & Cutillo, B. (1993). Spatiotemporal dynamics of component processes in human working memory. *Electroencephalography and Clinical Neurophysiology*, 87, 128–143.

Gray, J. R., & R., J. (2001). Emotional modulation of cognitive control: Approach-withdrawal states double-dissociate spatial from verbal two-back task performance. *Journal of*

Experimental Psychology: General, 130(3), 436–452. [https://doi.org/10.1037/0096-](https://doi.org/10.1037/0096-3445.130.3.436)

[3445.130.3.436](https://doi.org/10.1037/0096-3445.130.3.436)

Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences of the United*

States of America, 99(6), 4115–20. <https://doi.org/10.1073/pnas.062381899>

- Gross, J. J., & Levenson, R. W. (1995). Emotion Elicitation Using Films. *Cognition And Emotion*, 9(1), 87–108. Retrieved from [http://ist-socrates.berkeley.edu/~ucbpl/docs/48-Emotion Elicitation95.pdf](http://ist-socrates.berkeley.edu/~ucbpl/docs/48-EmotionElicitation95.pdf)
- Harmon-Jones, E., Gable, P. A., & Price, T. F. (2013). Does Negative Affect Always Narrow and Positive Affect Always Broaden the Mind? Considering the Influence of Motivational Intensity on Cognitive Scope. *Current Directions in Psychological Science*, 22(4), 301–307. <https://doi.org/10.1177/0963721413481353>
- Harmon-Jones, E., & Allen, J. J. B. (1997). Behavioral Activation Sensitivity and Resting Frontal EEG Asymmetry: Covariation of Putative Indicators Related to Risk for Mood Disorders. *Journal of Abnormal Psychology Copyright*, 106(1), 159–163.
- Harmon-Jones, E., & Allen, J. J. B. (1998). Anger and Frontal Brain Activity: EEG Asymmetry Consistent With Approach Motivation Despite Negative Affective Valence. *Journal of Personality and Social Psychology*, 74(5), 1310–1316.
- Harmon-Jones, E., Harmon-Jones, C., & Summerell, E. (2017). On the Importance of Both Dimensional and Discrete Models of Emotion. *Behavioral Sciences* ,66(7), <https://doi.org/10.3390/bs7040066>
- Heller, W., Nitschke, J. B., Miller, G. A., Greenough, W. T., Hwang, H. F., & Gorman, C. (1998). Lateralization in Emotion and Emotional Disorders The significance of biology for human development. *Current Directions in Psychological Science Annual Review of Neuro Science Child Psychology*, 7(1), 26–32.

- Hewig, J., Hagemann, D., Seifert, J., Gollwitzer, M., Naumann, E., & Bartussek, D. (2005). BRIEF REPORT A revised film set for the induction of basic emotions. *Cognition And Emotion, 19*(7), 1095–1109. <https://doi.org/10.1080/02699930541000084>
- Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review, 9*(4), 637–671. <https://doi.org/10.3758/BF03196323>
- Labar, K. S., & Phelps, E. A. (1998). AROUSAL-MEDIATED MEMORY CONSOLIDATION: Role of the Medial Temporal Lobe in Humans, *Psychological Science, 9*(6), 490-493.
- MacLean, M. H., & Arnell, K. M. (2010). Personality predicts temporal attention costs in the attentional blink paradigm. *Psychonomic Bulletin & Review, 17*(4), 556–562. <https://doi.org/10.3758/PBR.17.4.556>
- MacLean, M. H., Arnell, K. M., & Busseri, M. A. (2010). Dispositional affect predicts temporal attention costs in the attentional blink paradigm. *Cognition & Emotion, 24*(8), 1431–1438. <https://doi.org/10.1080/02699930903417897>
- Middlewood, B. L., Gallegos, J., & Gasper, K. (2016). Embracing the Unusual: Feeling Tired and Happy is Associated With Greater Acceptance of Atypical Ideas. *Creativity Research Journal, 28*(3), 310–317. <https://doi.org/10.1080/10400419.2016.1195639>

- Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping, 25*(1), 46–59. <https://doi.org/10.1002/hbm.20131>
- Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory*. *Perception & Psychophysics, 16*(2), 283–290.
- Postle, B. R., Berger, J. S., & D'Esposito, M. (1999). Functional neuroanatomical double dissociation of mnemonic and executive control processes contributing to working memory performance. *Proceedings of the National Academy of Sciences of the United States of America, 96*(22), 12959–64. <https://doi.org/10.1073/PNAS.96.22.12959>
- Postle, B. R. (2017). Working Memory Functions of the Prefrontal Cortex. In *The Prefrontal Cortex as an Executive, Emotional, and Social Brain* (pp. 39–48). Tokyo: Springer Japan. https://doi.org/10.1007/978-4-431-56508-6_3
- Postle, B., Awh, E., Jonides, J., & Smith, E. (2004). The where and how of attention-based rehearsal in spatial working memory. *Cognitive Brain Research, 20*(1), 194-205. <https://doi.org/10.1016/j.cogbrainres.2004.02.008>
- Postle, B. R., Desposito, M., & Corkin, S. (2005). Effects of verbal and nonverbal interference on spatial and object visual working memory. *Memory & Cognition, 33*(2), 203–12.
- Price, T. F., & Harmon-Jones, E. (2010). The Effect of Embodied Emotive States on Cognitive Categorization. *Emotion, 10*(6), 934-938. <https://doi.org/10.1037/a0019809>

- Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment, 28*(3), 164–171.
<https://doi.org/10.1027/1015-5759/a000123>
- Redick, T. S., & Lindsey, D. R. B. (2013). Complex span and n-back measures of working memory: A meta-analysis. *Psychonomic Bulletin Review, 20*(1), 1102–1113.
- Sala, S. Della, Gray, C., Baddeley, A., Allamano, N., & Wilson, L. (1998). Pattern span: a tool for unwelding visuo-spatial memory. *Neuropsychologia, 37*(1), 1189–1199.
- Shah, P., & Miyake, A. (1996). The Separability of Working Memory Resources for Spatial Thinking and Language Processing: An Individual Differences Approach. *Journal of Experimental Psychology: 125*(1), 4–27.
- Shipstead, Z., Lindsey, D. R. B., Marshall, R. L., & Engle, R. W. (2014). The mechanisms of working memory capacity: Primary memory, secondary memory, and attention control. *Journal of Memory and Language, 72*, 116–141. <https://doi.org/10.1016/j.jml.2014.01.004>
- Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science (New York, N.Y.), 283*(5408), 1657–61. <https://doi.org/10.1126/SCIENCE.283.5408.1657>
- Smith, E. E., Jonides, J., Koeppel, R. A., Awh, E., Schumacher, E. H., & Minoshima, S. (1995). Spatial versus Object Working Memory: PET Investigations. *Journal of Cognitive Neuroscience, 7*(3), 337–356. <https://doi.org/10.1162/jocn.1995.7.3.337>

- Storbeck, J. (2016). Is happiness a cure-all for mental fatigue?: mood interacts with situational requirements in predicting performance. *Motivation and Emotion*, *40*(3), 489–497.
<https://doi.org/10.1007/s11031-016-9547-9>
- Storbeck, J. (2012.). Performance Costs When Emotion Tunes Inappropriate Cognitive Abilities: Implications for Mental Resources and Behavior. *Journal of Experimental Psychology*, *141*(3), 411-416.
- Storbeck, J., & Maswood, R. (2016). Happiness increases verbal and spatial working memory capacity where sadness does not: Emotion, working memory and executive control. *Cognition and Emotion*, *30*(5), 925–938. <https://doi.org/10.1080/02699931.2015.1034091>
- Sutton, S. K., & Davidson, R. J. (1997). Prefrontal Brain Asymmetry: A Biological Substrate of the Behavioral Approach and Inhibition Systems. *Source: Psychological Science*, *8*(3), 204–210.
- Swanson, H. L. (2008). Working Memory and Intelligence in Children: What Develops? *Journal of Educational Psychology*, *100*(3), 581-602. <https://doi.org/10.1037/0022-0663.100.3.581>
- Swanson, H. L., & Fung, W. (2016). Working Memory Components and Problem-Solving Accuracy: Are There Multiple Pathways? *Journal of Educational Psychology*, *108*(8), 1153-1177. <https://doi.org/10.1037/edu0000116>
- Tellegen, A., Watson, D., Clark, L. A., & Clark, L. A. (1999). Further Support for a Hierarchical Model of Affect: Reply to Green and Salovey Reply to Green and Salovey. *Source: Psychological Science*, *10*(4), 307–309.

Unsworth, Heitz, Schrock, & Engle (2005). An automated version of the operation span task. *Behavior Research Methods*, 37, 498-505.

Unsworth, N., Fukuda, K., Awh, E., & Vogel, E. K. (2014). Working memory and fluid intelligence: Capacity, attention control, and secondary memory retrieval. *Cognitive Psychology*, 71, 1–26. <https://doi.org/10.1016/j.cogpsych.2014.01.003>

Vallar, G., Maria, A., Betta, D., & Silveri, M. C. (1996). The phonological short-term store rehearsal system. *Patterns of impairment and neural correlates*, 35(6), 684–701.

Vytal, K. E., Cornwell, B. R., Letkiewicz, A. M., Arkin, N. E., & Grillon, C. (2013). The complex interaction between anxiety and cognition: insight from spatial and verbal working memory. *Frontiers in Human Neuroscience*, 7, 93.
<https://doi.org/10.3389/fnhum.2013.00093>

Vytal, K., Cornwell, B., Arkin, N., & Grillon, C. (2012). Describing the interplay between anxiety and cognition: From impaired performance under low cognitive load to reduced anxiety under high load. *Psychophysiology*, 49(6), 842–852. <https://doi.org/10.1111/j.1469-8986.2012.01358.x>

Warrington, E. K., Logue, V., & Pratt, R. T. C. (1971). The Anatomical Localisation Of Selective Impairment Of Auditory Verbal Short-Term Memory. *Neuropsychologia*, (9), 377-387.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales. *Journal of Personality and Social Psychology*, 54(6), 1063–1070.

Yang, H., Yang, S., & Isen, A. M. (2013). Positive affect improves working memory: Implications for controlled cognitive processing. *Cognition And Emotion*, 27(3), 474–482.
<https://doi.org/10.1080/02699931.2012.713325>

Appendix A

The Circumplex Affect Questionnaire

Activation/ Deactivation

Participant #:

On the following pages, there are phrases describing people's behaviors. Please use the rating scale below to describe how accurately each statement describes you. Describe yourself as you generally are now, not as you wish to be in the future. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Please read each statement carefully, and then circle the response number which best corresponds with your behaviour.

Response Options

- 1: Strongly Disagree
- 2: Disagree
- 3: Neutral
- 4: Agree
- 5: Strongly Agree

1. At this moment, I feel nervous. 1 2 3 4 5
2. For some reason, I feel scared and afraid. 1 2 3 4 5
3. For some reason, I've been feeling sort of nervous. 1 2 3 4 5
4. I am feeling "unruffled." 1 2 3 4 5
5. I am feeling quiet. 1 2 3 4 5
6. I am feeling troubled. 1 2 3 4 5
7. I feel comfortable and content. 1 2 3 4 5
8. I feel content. 1 2 3 4 5
9. I feel determined. 1 2 3 4 5
10. Right now, I am sharp and attentive. 1 2 3 4 5
11. Right now, life feels like one big struggle. 1 2 3 4 5
12. Right now, life feels terrific. 1 2 3 4 5
13. Things are dull and boring. 1 2 3 4 5
14. Things feel pretty dull right now. 1 2 3 4 5
15. I feel disturbed and upset. 1 2 3 4 5
16. I feel droopy and drowsy. 1 2 3 4 5
17. I feel ecstatic. 1 2 3 4 5

18. I feel enthusiastic. 1 2 3 4 5
19. I feel exhausted. 1 2 3 4 5
20. I feel guilty about something that I have said or done. 1 2 3 4 5
21. I feel interested in what I am doing at the moment. 1 2 3 4 5
22. I feel irritated by something. 1 2 3 4 5
23. I feel jittery. 1 2 3 4 5
24. I feel on edge. 1 2 3 4 5
25. I feel peaceful. 1 2 3 4 5
26. I feel pleasantly at rest. 1 2 3 4 5
27. I feel powerful and strong. 1 2 3 4 5
28. I feel pretty enthusiastic about my life right now. 1 2 3 4 5
29. I feel proud of myself. 1 2 3 4 5
30. I feel rather distressed. 1 2 3 4 5
31. I feel set and determined about something right now. 1 2 3 4 5
32. I feel sluggish and slow. 1 2 3 4 5
33. I'm feeling inspired. 1 2 3 4 5
34. I'm feeling lively and cheerful. 1 2 3 4 5
35. I'm feeling placid, low in energy. 1 2 3 4 5
36. I am full of guilt and remorse. 1 2 3 4 5
37. I am happy. 1 2 3 4 5
38. I am satisfied. 1 2 3 4 5
39. I am stirred up. 1 2 3 4 5
40. I am unhappy. 1 2 3 4 5
41. I feel alive and active. 1 2 3 4 5
42. I feel angry. 1 2 3 4 5
43. I feel ashamed of myself. 1 2 3 4 5
44. I feel at ease. 1 2 3 4 5
45. I feel calm and relaxed. 1 2 3 4 5
46. I feel calm, cool, and collected. 1 2 3 4 5
47. I'm feeling pleasantly well-rested. 1 2 3 4 5
48. I'm feeling pretty angry at the moment. 1 2 3 4 5

49. I'm feeling sluggish and dragged out. 1 2 3 4 5
50. I'm feeling stirred up. 1 2 3 4 5
51. I'm feeling untroubled and comfortable. 1 2 3 4 5
52. I'm filled with energy. 1 2 3 4 5
53. I'm full of energy and tension 1 2 3 4 5
54. I'm having some trouble paying attention. 1 2 3 4 5
55. I'm keyed up. 1 2 3 4 5
56. I'm too relaxed to worry about anything. 1 2 3 4 5
57. My body feels activated. 1 2 3 4 5
58. My body feels still. 1 2 3 4 5
59. My body is in a quiet, still state. 1 2 3 4 5
60. I feel tired. 1 2 3 4 5
61. I feel unhappy. 1 2 3 4 5
62. I feel very focused and on task. 1 2 3 4 5
63. I feel very inspired. 1 2 3 4 5
64. I feel worried. 1 2 3 4 5
65. I have little interest in things around me. 1 2 3 4 5
66. I'm bothered by something. 1 2 3 4 5
67. I'm dissatisfied. 1 2 3 4 5
68. I'm exhausted. 1 2 3 4 5
69. I'm feeling energetic and positive. 1 2 3 4 5
70. My internal engine is running slow and smoothly. 1 2 3 4 5
71. My mind and body are resting, near sleep. 1 2 3 4 5
72. My mood is not good. 1 2 3 4 5
73. My mood is positive. 1 2 3 4 5
74. Overall, I am satisfied. 1 2 3 4 5
75. Right now, everything feels dull and boring. 1 2 3 4 5
76. Right now, I am at ease with things. 1 2 3 4 5
77. I'm miserable. 1 2 3 4 5

Appendix B

The Emotion Report Form

STATE MEASURE

Indicate to the degree to which you are currently experiencing each of the different emotions shown below. Use the following scale to record your answers.

0	1	2	3	4	5	6	7	8
None								A great deal

	Amusement
	Anger
	Anxiety
	Contentment
	Disgust
	Fear
	Happiness
	Joy
	Sadness
	Serenity

Appendix C

Affect and Cognitive Performance Consent Form

Consent to Participate in Research Psychology Department, Brock University, 2017-2018 Affect and Cognitive Performance

Invitation to Participate

You are invited to participate in this research study of mood and cognition being conducted by Dr. Karen Arnell and Andrew Chung. Dr. Karen Arnell is a Professor in the Department of Psychology at Brock University. She can be reached by phone at (905) 688-5550 ext. 3225. The Psychology Department can be reached by phone at (905) 688-5550 ext.5050, or by email at lindap@brocku.ca. This study has received ethics clearance (REB #) from the Brock University Research Ethics Board, and is funded by the Natural Sciences and Engineering Research Council (NSERC).

Basis for Participant Selection

In this study, you will be asked to complete a variety of English based questionnaires. If you do not have English as a first language, you will not be able to participate. Also, you will be asked to complete working memory tasks that involve viewing words and patterns. If you do not have normal or corrected-to-normal visual acuity (e.g., glasses or contacts), you will not be able to participate. The study examines how mood influences your cognition. Individuals on mood altering medications such as anti-anxiety or anti-depressive medications will not be able to participate. Please tell the experimenter now if one of these exclusion criteria applies to you (you do not have to disclose which one). If you are not comfortable with these material, you are able to withdraw from the study at any moment without penalty.

Overall Purpose of the Study

Your participation will help us learn more about how our minds organize information and how this may relate to your everyday emotions and behaviours. In this study, Ultimately, we hope to learn more about the links between affect and cognition.

Explanation of Procedures

The study will be conducted in this room, and will take approximately 2 hours to complete.

Timeline

- 1. (5 minutes)** You will be asked to review our consent procedures.
- 2. (25 minutes)** You will be asked to complete 5 questionnaires about your everyday emotions and behaviours.
- 3. (30 minutes)** You will be asked to complete 3 computer based Memory Tasks.
- 4. (2 minutes)** - Break
- 5. (30 minutes)** You will be asked to complete 3 computer based Memory Tasks.

6. (5 minutes) We will describe the purpose of the study and answer any questions you may have.

Potential Risks and Discomforts

You may experience mild fatigue while completing the questionnaires and completing the cognitive tasks. A short break will be given before completing the second set of cognitive tasks. If you are uncomfortable with performing one or more of the tasks or answering one or more of the questions on the questionnaires, you can choose to simply skip that portion of the study without penalty.

Potential Benefits

This research will help us help us learn more about how our minds are influenced by our consistent emotions and motivations. If you are not familiar with cognitive psychology, then the experiment will expose you to a new area of psychology.

Compensation for Participation

For your participation today you will receive 2 hours of research participation toward any participating Brock University course.

Assurance of Confidentiality

Both the cognitive tasks and self-report information we collect from you in this study (your responses) will be coded by a number, not your name. Your identity will not be revealed or connected with the experimental results or participant number. We are interested in combining data from all of the participants, not in reporting the pattern for each person. Your data will be combined with the data from other participants, and reported in summary form. Data and records created by this project are the property of the University and the investigator. You may have access to the overall results of the experiment by making a written request to Dr. Karen Arnell (karnell@brocku.ca). A copy of the summary results will then be sent to you when the experiment has been completed. This right of access extends only to the data combined from all participants, and not to your individual data nor the individual data of other participants.

Data will be secured either in a locked cabinet (paper data) or on password protected computers (electronic data files for SPSS analysis) in a locked and alarmed lab that can only be accessed by Dr. Arnell, and her research students and research assistants. Data will be kept for 7 years from the date of the last journal publication (as per APA requirements). Once the 7 year period has passed, paper data will be deposited in padlocked confidential shredding bins that are periodically deposited in the Psychology department at Brock. Electronic data will be deleted from the hard drive and once the computer no longer works it will be disposed of through ITS at Brock.

Withdrawal from the Study

Your participation is voluntary, and you may withdraw from the study at any time without penalty. Your decision of whether or not to participate will not affect your course grades or your eligibility for other studies. If you decide to participate now, you are free to withdraw your consent and to discontinue participation at any time during testing. Note that this may reduce confidentiality as the experimenter will know you withdrew and that they are shredding your data. In the event of withdrawal, you will still receive the research feedback form and have the opportunity to ask questions at the end of the session. You will still receive full compensation.

The data of the participants who choose to withdraw from this study will be fed into the shredder by the experimenter. It is not possible to withdraw from the study after submitting data.

Offer to Answer Questions

You should feel free to ask the experimenter questions now or at any time during the study. If you have further questions or concerns, at any time you can contact Dr. Karen Arnell, at (905) 688-5550 ext. 3225 or karnell@brocku.ca. If you have questions about the rights of research participants, contact the Brock Research Ethics Officer in the Office of Research Services (905) 688-5550 ext. 3035.

Consent Statement

The procedures and potential harms/benefits have now been explained to you. You are voluntarily making a decision about whether or not to participate in the study. Your signature below indicates that you have freely decided to participate in this research study, having read and understood all of the information above, and understanding that you may ask questions now and in the future.

Print full name of participant	Signature of participant	Date
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Age	Sex (M/F)	Signature of Researcher
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I am participating in this experiment for 120 minutes (two hours) of research participation in a Brock University course and will not receive monetary payment for this experiment.

Signature of participant	Course	Signature of Researcher
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Thank you for your participation in this study. Please keep a copy of the consent form for your records.

Appendix D

Correlations Between Affect Valence and the Individual Working Memory Tasks

Variable	GVerbal	GSpatial	NGVerbal	NGSpatial	ReadingSpan	SymmetrySpan
Trait Positive	.19	.06	.12	.34**	.09	.13
Trait Negative	-.16	-.05	-.19	-.21	-.11	.02
Trait Valence	.18	.08	.17	.30*	.12	.06
State Positive	.04	-.03	.10	.24	.07	.13
State Negative	-.22	-.12	-.38**	-.39**	-.20	-.06
State Valence	.17	.06	.30*	-.38**	.17	.16

Note: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Trait Positive refers to the average of all pleasant items from the Circumplex Affect Questionnaire. Trait negative refers to the average of all unpleasant items from the Circumplex Affect Questionnaire. Trait valence refers to the pleasant average minus the unpleasant average from the Circumplex Affect Questionnaire. State positive refers to averaged positive adjective scores on the Emotion Report Form. State negative refers to averaged negative items on the Emotion Report Form. State valence refers to the positive score minus the negative score from the Emotion Report Form. All 2-back tasks are expressed as percentage hits minus percentage false alarms out of all presented trials. Gray verbal 2-back task (GVerbal), and Gray spatial 2-back task (GSpatial). Non-Gray versions of 2-back tasks are denoted by NG (i.e., NGVerbal, NSpatial). Reading Span partial credit score (ReadingSpan). For the Reading Span, 75 is the maximum score that can be achieved. Symmetry Span partial credit score (SymmetrySpan). For the Symmetry Span, 42 is the maximum score that can be achieved.